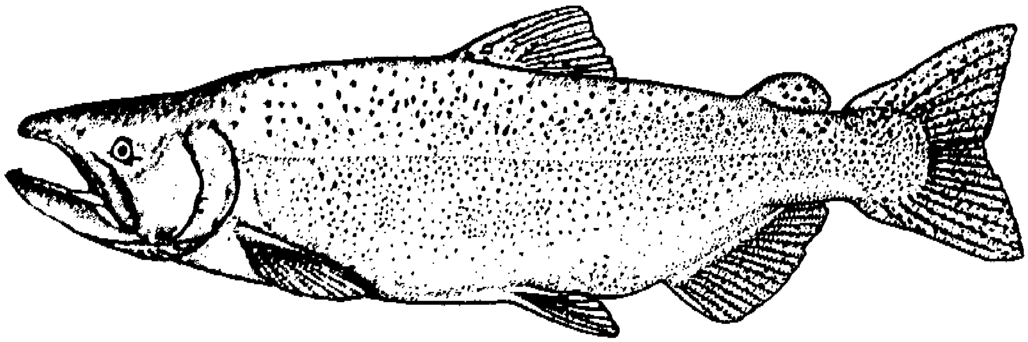
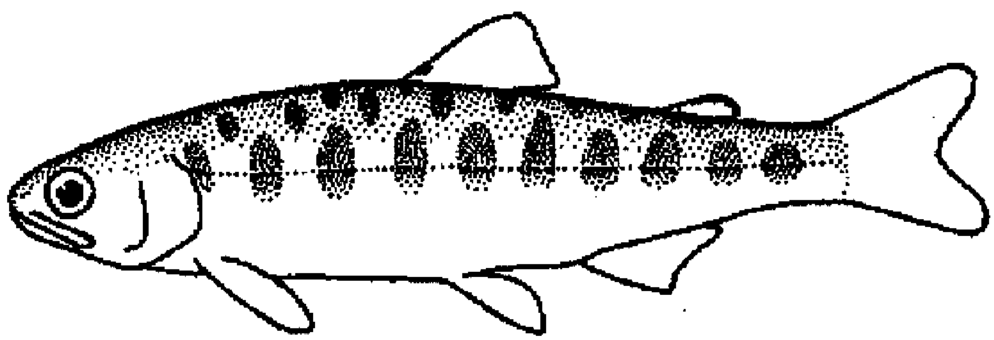
MONITORING OF RESTORATION PROJECTS IN THE MERCED RIVER USING 2-DIMENSIONAL MODELING METHODOLOGY





U. S. Fish and Wildlife Service
Sacramento Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, California 95825

Prepared by staff of
The Energy Planning and Instream Flow Branch

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PREFACE

This report was prepared as part of the Merced River Restoration Project Monitoring Investigations, a 4-year effort which began July 2000. Funding was provided under Title 34, section 3406(b)(1) of the Central Valley Project Improvement Act, P.L. 102-575, for channel restoration of the Merced River to provide spawning, incubation, and rearing habitat for fall-run Chinook salmon. The purpose of this investigation is to evaluate the success of these restoration activities.

To those who are interested, comments and information regarding this program and the habitat resources of Central Valley rivers are welcomed. Written comments or information can be submitted to:

Mark Gard, Senior Biologist
Energy Planning and Instream Flow Branch
U.S. Fish and Wildlife Service
Sacramento Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, CA 95825

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INTRODUCTION

The decline of fall-run Chinook salmon in the Merced River over the last decade is attributed to many factors including habitat degradation. The existing habitat appears unfavorable for either spawning or rearing (U.S. Fish and Wildlife Service 2001). Funding was provided under the Central Valley Project Improvement Act (CVPIA), section 3406(b)(1), for channel restoration of the Merced River to provide spawning, incubation, and rearing habitat for fall-run Chinook salmon. The Merced River Study was a 4-year effort that was completed in two phases (pre-restoration and post-restoration) in 2003. The study described herein involves application of the U.S. Fish and Wildlife Service (Service) Instream Flow Incremental Methodology to compare total weighted usable area of fall-run Chinook salmon habitat before and after channel restoration using 2-D modeling. The restoration reach is about 1.5 miles long and is located at River Mile 42-43.5, 10 miles downstream of Crocker-Huffman Dam.

A 2-dimensional hydraulic and habitat model (RIVER2D) was used for this modeling, instead of the Physical Habitat Simulation (PHABSIM[1]) component of the Instream Flow Incremental Methodology (IFIM). The 2-D model uses as inputs the bed topography and substrate of a site, and the water surface elevation at the bottom of the site, to predict the amount of habitat present in the site. The 2-D model avoids problems of transect placement, since data is collected uniformly across the entire site. The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than PHABSIM because it takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's Equation and a velocity adjustment factor. Other advantages of 2-D modeling are that it can explicitly handle complex hydraulics, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions. The model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model, with compact cells, will be more accurate than PHABSIM, with long rectangular cells, in capturing longitudinal variation in depth, velocity, substrate and cover. The 2-D model does a better job of representing patchy microhabitat features, such as gravel patches. The data can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate. Bed topography and substrate mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the top and bottom of the site and flow and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

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[1] PHABSIM is the collection of one dimensional hydraulic and habitat models which are used to predict the relationship between physical habitat availability and streamflow over a range of river discharges.

METHODS

Study Site Selection

In July 2000, four study sites were selected for the pre-restoration phase of the study within the 1.5 mile long Robinson Restoration area on the Merced River. Three of these sites were located in a portion of the reach where the river was split into multiple channels; the sites were located on one of the channels. In the same reach of the river, four sites were selected for the post-restoration phase of the study in June 2002. The characteristics of the study sites are given in Table 1. The upper portion of post-restoration site 1 was above the restoration area to serve as a control. Data collection for the pre-restoration phase of the study was completed by March 2001. Data collection for the post-restoration phase of the study was completed by April 2003.

Table 1
Characteristics of Study Sites

Site Name Pre-restoration	Site length (ft)	Mean site width (ft)	Mean site bed slope
Site 1	1622	183	0.39%
Site 2	222	218	0.02%
Site 3	140	200	0.82%
Site 4	191	314	0.007%
Post-restoration			
Site 1	1019	152	0.44%
Site 2	838	120	0.25%
Site 3	205	175	0.002%
Site 4	870	120	0.13%

Transect Placement (study site setup)

The pre-restoration study sites were established in August 2000. The post-restoration study sites were established in August 2002. For each study site, a transect was placed at the top (upstream) and bottom (downstream) of the site. The downstream transect was modeled using the hydraulic simulation in PHABSIM to provide water surface elevations as an input to the 2-D model. The upstream transect was used in calibrating the 2-D model - bed roughnesses are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. Transect pins (headpins and tailpins) were marked on each river bank above the 3000 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

Hydraulic and Structural Data Collection

Vertical benchmarks were established at each site to serve as the reference elevation to which all elevations (streambed and water surface) were tied. In addition, horizontal benchmarks were established at each site to serve as reference locations to which all horizontal locations (northings and eastings) were tied. Engineers for the restoration project established total station control points previous to the start of our post-restoration IFIM work. Our vertical and horizontal benchmarks for the post-restoration sites were tied into these points.

The data collected at the upstream (transect 2) and downstream (transect 1) transects include: 1) water surface elevations (WSELs), measured to the nearest .01 foot at four to five different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a high-to-mid range flow at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. Table 2 gives the substrate codes and size classes used in this study. Table 3 gives the cover codes and categories used in this study.

We collected the data between the top and bottom transects by obtaining the bed elevation and horizontal location of individual points with a total station, while the cover and substrate were visually assessed at each point. These parameters are collected at enough points to characterize the bed topography, substrate and cover of the site. The number and density of points collected for each of the pre- and post-restoration study sites is given in Table 4. Substrate and cover along the transects were also determined visually. To validate the velocities predicted by the 2-D model, depth, velocities, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 velocity meter or a Price-AA velocity meter equipped with a current meter digitizer. These validation velocities and the velocities measured on the transects described previously were collected at 0.6 of the depth for 20 seconds. The horizontal locations and bed elevations were determined by taking a total station shot on a prism held at each point where depth and velocity were measured. A minimum of 50 representative points were measured per site.

Table 2
Substrate Descriptors and Codes

Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1
1	Small Gravel	0.1 - 1
1.2	Medium Gravel	1 - 2
1.3	Medium/Large Gravel	1 - 3
2.3	Large Gravel	2 - 3
2.4	Gravel/Cobble	2 - 4
3.4	Small Cobble	3 - 4
3.5	Small Cobble	3 - 5
4.5	Medium Cobble	4 - 5
4.6	Medium Cobble	4 - 6
6.8	Large Cobble	6 - 8
8	Large Cobble	8 - 10
9	Boulder/Bedrock	> 12
10	Large Cobble	10 - 12

Phase 1. Pre-restoration

Hydraulic and structural data collection began in August 2000 and was completed in October 2000. Water surface elevations were collected at four flows (108-146, 452-472, 865-879 and 1162 cfs) for all four sites. Discharge measurements were collected at all sites for the three lower flow levels, while wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 velocity meter or a Price-AA velocity meter equipped with a current meter digitizer. The discharge for the highest flow was determined from a California Department of Water Resources gage. Sites 2, 3 and 4 did not contain the entire Merced River flow; the measurements of discharge at these sites were used to develop regression equations to predict the flow at these sites from the total Merced River flow.

Table 3
Cover Coding System

Cover Category	Cover Code[2]
no cover	0.1
cobble	1
boulder	2
fine woody vegetation (< 1" diameter)	3
branches	4
log (> 1' diameter)	5
overhead cover (> 2' above substrate)	7
undercut bank	8
aquatic vegetation	9
rip-rap	10

Phase 2. Post-restoration

Hydraulic and structural data collection began in August 2002 and was completed in December 2002. Water surface elevations were collected for the four post-restoration sites at four to five flows (134, 198, 379, 468 and 1047 cfs). Discharge measurements were collected at all five flow levels, while wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 velocity meter or a Price-AA velocity meter equipped with a current meter digitizer. The flow was the same for all four sites.

Biological Validation Data Collection

The horizontal location of fall-run Chinook salmon redds in the study sites was recorded on November 13, 2000, for the pre-restoration sites and on December 2-3, 2002, for the post-restoration sites, by sighting from the total station to a stadia rod and prism. Redds were located on foot and all active

[2] In addition to these cover codes, we have been using composite cover codes (3.7, 4.7, 5.7 and 9.7); for example, 4.7 would be branches plus overhead cover.

Table 4
Number and Density of Data points Collected for Each Site

Site Name Pre-restoration	Number of Points on Transects	Number of Points Between Transects	Density of Points (points/100 m^2)
Site 1	88	682	2.8
Site 2	78	235	7.0
Site 3	91	142	8.9
Site 4	133	279	7.4
Post-restoration			
Site 1	65	348	2.9
Site 2	66	294	3.8
Site 3	58	168	6.8
Site 4	59	383	4.6

redds (those not covered by periphyton growth) within a given site were measured. Depth, velocity, and substrate size were measured for each redd. Data were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. This location was generally about 5-7 feet upstream of the pit of the redd; however in one case it was necessary to make measurements at a 45 degree angle upstream. The data were all collected within 9 feet of the pit of the redd. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. Measurements were taken with a wading rod equipped with a Marsh-McBirney[R] model 2000 velocity meter or a Price-AA velocity meter equipped with a current meter digitizer. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2 inches) at three locations: 1) in front of the pit; 2) on the sides of the pit; and 3) in the tailspill. We found a total of 5 redds in the pre-restoration sites and 43 redds in the post-restoration sites. All data were entered into spreadsheets. These data were collected to test the hypothesis that the compound suitability predicted by the River2D model is higher at locations where redds were present versus locations where redds were absent. This hypothesis was statistically tested with a Mann-Whitney U test.

We conducted snorkel surveys of the pre-restoration sites on January 31-February 1 and March 19-20, 2001, and of the post-restoration sites on March 11 and April 21-22, 2003, to determine the location of young-of-the-year fall-run Chinook salmon. Two to three snorkelers would move upstream through the study sites, placing a weighted, numbered tag at each location where young-of-the-year

Chinook salmon were observed. The snorkelers recorded the tag number, the cover code[3] and the number of individuals observed in each 10-20 mm size class on a Poly Vinyl Chloride (PVC) wrist cuff. Following the snorkel survey, the horizontal location of each tag was recorded by sighting from the total station to a stadia rod and prism, and the depth, velocity and adjacent velocity[4] was measured at each tag location. Depth was recorded to the nearest 0.1 ft and average water column velocity and adjacent velocity were recorded to the nearest 0.01 ft/s. Data taken by the snorkeler and the measurer were correlated at each tag location. We made a total of 57 observations of young-of-the-year Chinook salmon (all fry) in the pre-restoration sites[5] and 29 observations of young-of-the-year Chinook salmon (19 fry and 13 juvenile) in the post-restoration sites. All data were entered into spreadsheets. These data were collected to test the hypothesis that the compound suitability predicted by the River2D model is higher at locations where young-of-the-year Chinook salmon were present versus locations where young-of-the-year were absent. This hypothesis was tested with a Mann-Whitney U test.

Habitat Mapping

The entire pre-restoration and post-restoration reaches were habitat-typed to be able to extrapolate the results from the study sites to the entire restoration reach. The pre-restoration reach was habitat-typed on January 30 and March 21, 2001, while the post-restoration reach was habitat-typed on September 10, 2002. We used the following habitat types for both the pre-restoration and post-restoration reaches: run, glide, pool, low-gradient riffle and high-gradient riffle. We used an additional two habitat types for the pre-restoration reach: gravel pit and sheet flow. Gravel pits were areas where the river

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[3] If there was no cover elements (as defined in Table 3) within 1 foot horizontally of the fish location, the cover code was 0.1 (no cover).

[4] The adjacent velocity was measured within 2 feet on either side of the location where the velocity was the highest. Two feet was selected based on a mechanism of turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon and steelhead/rainbow trout reside, taking into account that the size of turbulent eddies is approximately one-half of the mean river depth (Terry Waddle, USGS, personal communication), and assuming that the mean depth of the Merced River is around 4 feet (i.e., 4 feet x ½ = 2 feet). This measurement was taken because an alternative habitat model was used which considers adjacent velocities in assessing habitat quality. Adjacent velocity can be an important habitat variable as fish, particularly fry and juveniles, frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed. Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth.

[5] Five of the observations were actually upstream of the sites. Thus, there were actually 52 observations of Chinook salmon fry in the pre-restoration sites.

flowed through a deep abandoned gravel pit, while sheet flow was areas where the river had broken out of the levees and crossed a wide, shallow area. Pools were characterized by the presence of a downstream hydraulic control, riffles were characterized by shallow, fast conditions, runs were characterized by deeper conditions with surface turbulence, and glides were classified based on having a glassy water surface. The length of each habitat unit was measured with an electronic distance meter. During the habitat typing, the distribution of habitat types in each study site was mapped. The results of the habitat typing are shown in Table 5.

Table 5
Total Length (feet) and Proportion of Habitat Types

	Pre-Restoration				Post-Restoration			
Habitat Type	**Reach**		**Sites**		**Reach**		**Sites**[6]	
Glide	762	9%	198	9%	462	6%	172	6%
Low-gradient riffle	1186	14%	244	11%	2139	26%	601	22%
High-gradient riffle	447	5%	305	14%	0	0%	0	0%
Run	1363	16%	833	38%	2169	26%	807	30%
Pool	2366	27%	189	9%	3571	43%	1109	41%
Gravel Pit	1093	13%	191	9%	0	0%	0	0%
Sheet Flow	1519	17%	222	10%	0	0%	0	0%

Hydraulic Model Construction and Calibration

All data were compiled and checked before entry into PHABSIM data files. A table of substrate and cover ranges/values was created to determine the substrate and cover for each vertical (e.g, if the substrate size class was 2-4 inches on a transect from station 50 to 70, all of the verticals with station values between 50 and 70 were given a substrate coding of 2.4). Dry bed elevation data in field notebooks were entered into the spreadsheet to extend the bed profile up the banks above the WSEL

[6] The upper portion of Post-Restoration Site 1 also included 137 feet of pre-restoration low-gradient riffle, 87 feet of pre-restoration high-gradient riffle and 149 feet of pre-restoration run.

of the highest flow to be modeled. An ASCII file produced from the spreadsheet was run through the FLOMANN program (written by Andy Hamilton) to get the PHABSIM input file and then translated into RHABSIM[7] files.

All of the measured WSELs were checked showing that there was no uphill movement of water. The WSELs measured at the lowest flow for post-restoration site 3 were not used because they were higher than the WSELs at the next higher flow. The WSEL measured at the lowest flow for the upper transect for post-restoration site 4 was not used because it was only 0.11 foot higher than the WSEL measured at the downstream transect, while the WSELs measured at the other flows at the upper transect were over a foot higher than the respective WSELs at the downstream transect. We concluded that the above WSELs were measured incorrectly.

The slope for each transect was computed at each measured flow as the difference in WSELs between the two transects divided by the distance between them. The slope used for each transect was calculated by averaging the slopes computed for each flow. A separate deck was constructed for each study site. The stage of zero flow (SZF), an important parameter used in calibrating the stage-discharge relationship, was determined for each transect and entered. In habitat types without backwater effects (e.g., riffles and runs), this value generally represents the lowest point in the streambed across a transect. However, if the upstream transect contains a lower bed elevation than the downstream transect, the SZF for the downstream transect applies to both. For downstream transects with backwater effects, the SZF value was measured by determining, using differential leveling, the highest bed elevation on the thalweg downstream of the site. For sites where the hydraulic control for the upstream transect was located within the site, the SZF (the thalweg elevation at the hydraulic control) was determined from the bed topography data collected for the 2-D model.

Calibration flows in the data files (Appendix A) were the flows measured at one or more locations. Where the flow was measured at more than one location, the average of the measurements was taken as the calibration flow. Flow/flow regressions were performed for pre-restoration sites 2, 3 and 4, since they did not include the entire flow, using the flow measured at each site and the total river flow, measured at pre-restoration site 1. The regressions were developed from three to four sets of flows, with the entire river discharge at 108-146 cfs, 452-472 cfs and 865-879 cfs. Calibration flows for pre-restoration sites 2, 3 and 4 were calculated from the total discharge and the appropriate regression equation in Table 6.

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[7] RHABSIM is a commercially-produced software (Payne and Associates 1998) that incorporates the modeling procedures used in PHABSIM.

Table 6
Flow/Flow Regression Equations

Pre-restoration Study Site	Regression Equation[8]	R^2-value
2	Site 2 Q = -11 + 0.93 x Q	0.996
3	Site 3 Q = -6 + 0.63 x Q	0.953
4	Site 4 Q = 35 + 0.65 x Q	0.999

The first step in the calibration procedure was to determine the best approach for WSEL simulation. Initially, the *IFG4* hydraulic model (Milhous *et al.* 1989) was run on each deck to compare predicted and measured WSELs. This model produces a stage-discharge relationship using a log-log linear rating curve calculated from at least three sets of measurements taken at different flows. Besides *IFG4*, two other hydraulic models are available in PHABSIM to predict stage-discharge relationships. These models are: 1) *MANSQ*, which operates under the assumption that the condition of the channel and the nature of the streambed controls WSELs; and 2) *WSP*, the water surface profile model, which calculates the energy loss between transects to determine WSELs. *MANSQ*, like *IFG4*, evaluates each transect independently. *WSP* must, by nature, link at least two adjacent transects. *IFG4,* the most versatile of these models, is considered to have worked well if the following criteria are met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot difference between measured and simulated WSELs[9]. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a 0.1 foot difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*.

For most of the transects, we needed to simulate low and high flows with different sets of calibration WSELs (Appendix A) to meet the above criteria. For transects where we had measured five sets of WSELs, *IFG4* could be run for low flows using the three lowest calibration WSELs, and run for high

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[8] Q is the total river flow, Site 2 Q is the flow in Site 2, etc.

[9] The first three criteria are from U.S. Fish and Wildlife Service (1994), while the fourth criterion is our own criterion.

flows using the three highest calibration WSELs. For transects where we had only measured four sets of WSELs, we typically used *IFG4* with the three highest or three lowest flows to simulate, respectively, the high or low flows, and used *MANSQ* or *WSP* with the two lowest or two highest flows to simulate the remaining flows.

For a majority of the transects in the pre- and post-restoration study sites, *IFG4* met the above criteria (Appendix A). The only exceptions were: 1) for low flows for pre-restoration site 2 transect 1, where the mean error was 11.2% and the difference between the measured and simulated WSELs at the middle flow was 0.13 foot; 2) for low flows for both transects at pre-restoration site 4 where the beta value equaled 1.84; 3) for low flows for both transects at post-restoration site 3 where the beta value was 1.39-1.40; and 4) for low flows for post-restoration site 4 transect 1, where the beta value was 1.98. In the first case, we still used *IFG4* because *MANSQ* gave much greater errors and because *WSP* cannot be used at the downstream transect. We concluded that the low beta values for the other three cases were caused by channel characteristics which form hydraulic controls at some flows but not others (compound controls), thus affecting upstream water elevations. Specifically, at lower flows the channel at these transects controlled the water surface elevations, while at higher flows the water surface elevations were controlled by downstream hydraulic controls. Accordingly, the performance of *IFG4* for these transects was considered adequate despite the beta coefficient criterion not being met. *MANSQ* worked successfully for pre-restoration site 3 transect 1, for high flows for pre-restoration site 4 transect 1, at high flows for both transects of post-restoration site 3, and at high flows for post-restoration site 4 transect 2, meeting the above criteria for *MANSQ* (Appendix A). For high flows for post-restoration site 1 transect 2, *MANSQ* did not meet the mean error criterion, with a mean error of 14.1%. We still used *MANSQ* for this transect because *IFG4* and *WSP* gave much greater errors. *WSP* worked successfully for low flows at pre-restoration site 2 transect 2 and at high flows for pre-restoration site 4 transect 2, with the above *WSP* criteria being met (Appendix A).

The final step in simulating WSELs was to check whether water was going uphill at any of the simulated WSELs. This only occurred for flows above 1050 cfs at post-restoration site 3 transect 2. There was a very low WSEL gradient for this site; accordingly, we used *WSP* for high flows at this transect by setting the simulated WSELs for the transect equal to the WSEL at post-restoration site 3 transect 1.

Velocity Adjustment Factors (VAFs) were examined for all of the simulated flows (Appendix B). None of the pre-or post-restoration study site transects deviated significantly from the expected pattern of VAFs. Post-restoration site 3 transect 2 at low flows had minor deviations from the expected pattern of VAFs; we attribute the pattern in this case to compound controls, and thus the patterns of VAFs for all transects was acceptable. In addition, the VAF values (ranging from 0.58 to 59.35) were all within an acceptable range except for flows above 2300 cfs at pre-restoration site 2 transect 1, flows above 700 cfs at pre-restoration site 2 transect 2, flows above 2100 cfs at pre-restoration site 4 transect 1, and at all flows for pre-restoration site 4 transect 2 (Appendix B).[10] The high VAF values for the above sites are due to strong backwater effects caused by hydraulic controls (crests of riffles) downstream of the sites and (for both of the upstream transects) a erroneously low discharge measured for the velocity sets for these transects. This is acceptable in this case since RHABSIM is only being used to simulate WSELs and not velocities. The velocity set discharge for the upstream transects for pre-restoration sites 2 and 4 were not used to calculate the site discharge used to develop the flow/flow regressions in Table 6.

The dry/shallow total station data and the PHABSIM transect data were combined in a spreadsheet to create the input files (bed and substrate) for the 2-D modeling program. The bed files contain the horizontal location (northing and easting), bed elevation and initial bed roughness value for each point, while the substrate files contain the horizontal location, bed elevation and substrate code for each point. An artificial extension one channel-width-long was added upstream of the top of the site to enable the flow to be distributed by the model when it reached the study area, thus minimizing boundary conditions influencing the flow distribution at the upsteam transect and within the study site. The initial bed roughness value for each point was determined from the substrate and cover codes for that point and the corresponding bed roughness values in Table 7, with the bed roughness value computed as the sum of the substrate bed roughness value and the cover bed roughness value. The bed roughness values for substrate in Table 7 were computed as five times the average particle size[11]. The bed roughness values for cover in Table 7 were computed as five times the average cover size, where the cover size was measured on the Sacramento River on a representative sample of cover elements of each cover type. The bed and substrate files were exported from the spreadsheet as ASCII files.

A utility program, R2D_BED (Steffler 2001b), was used to define the study area boundary and to refine the raw topographical data TIN (triangulated irregular network) by defining breaklines[12] following longitudinal features such as thalwegs, tops of bars and bottoms of banks. Breaklines were also added along lines of constant elevation. The bed topography of the sites is shown in Appendix C.

An additional utility program, R2D_MESH (Steffler 2001a), was used to define the inflow and outflow boundaries and create the finite element computational mesh for the River2D model. R2D_MESH uses the final bed files as an input. The first stage in creating the computational mesh was to define mesh

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[10] VAFs are considered acceptable if they fall within the range of 0.2 to 5.0.

[11] Five times the average particle size is approximately the same as 2 to 3 times the d85 particle size, which is recommended as an estimate of bed roughness height (Yalin 1977).

[12] Breaklines are a feature of the R2D_Bed program which force the TIN of the bed nodes to linearly interpolate bed elevation and bed roughness values between the nodes on each breakline and force the TIN to fall on the breaklines (Steffler 2001b).

Table 7
Initial Bed Roughness Values[13]

Substrate Code	Bed Roughness (m)	Cover Code	Bed Roughness (m)
0.1	0.05	0.1	0
1	0.1	1	0
1.2	0.2	2	0
1.3	0.25	3	0.11
2.3	0.3	3.7	0.2
2.4	0.4	4	0.62
3.4	0.45	4.7	0.96
3.5	0.5	5	1.93
4.6	0.65	5.7	2.59
6.8	0.9	7	0.28
8	1.25	8	2.97
9	0.05	9	0.29
10	1.4	9.7	0.57
		10	3.05

breaklines[14] which coincided with the final bed file breaklines. Additional mesh breaklines were then added between the initial mesh breaklines, and additional nodes were added as needed to improve the

[13] For substrate code 9, we used bed roughnesses of 0.71 and 1.95, respectively, for cover codes 1 and 2. Bed roughnesses of zero were used for cover codes 1 and 2 for all other substrate codes, since the roughness associated with the cover was included in the substrate roughness.

[14] Mesh breaklines are a feature of the R2D_MESH program which force edges of the computation mesh elements to fall on the mesh breaklines and force the TIN of the computational mesh to linearly interpolate the bed elevation and bed roughness values of mesh nodes between the nodes at the end of each breakline segment (Steffler 2001a). A better fit between the bed and mesh TINs is achieved by having the mesh and bed breaklines coincide.

it between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. The QI is a measure of how much the least equilateral mesh element deviates from an equilateral triangle. An ideal mesh (all equilateral triangles) would have a QI of 1.0. A QI value of at least 0.2 is considered acceptable (Steffler 2001a). As shown in Appendix D, the meshes for all sites had QI values of at least 0.3. In addition, the difference in bed elevation between the mesh and final bed file was less than 0.1 foot (0.03 m) for most of the area of all sites. The percentage of the original bed nodes for which the mesh differed by less than 0.1 foot (0.03 m) from the elevation of the original bed nodes ranged from 72% to 92% (Appendix D). In most cases, the areas of the mesh where there was greater than a 0.1 foot (0.03 m) difference between the mesh and final bed file were in steep areas; in these areas, the mesh would be within 0.1 foot (0.03 m) vertically of the bed file within 1 foot (0.3 m) horizontally of the bed file location. Given that we had a one-foot (0.3 m) horizontal level of accuracy, such areas would have an adequate fit of the mesh to the bed file. The final step with the R2D_MESH software was to generate the computational (cdg) files.

The cdg files were opened in the RIVER2D software, where the computational bed topography mesh was used together with the WSEL at the bottom of the site, the flow entering the site, and the bed roughnesses of the computational mesh elements to compute the depths, velocities and WSELs throughout the site. The basis for the current form of RIVER2D is given in Ghanem et al (1995). The computational mesh was run to steady state at the highest flow to be simulated, and the WSELs predicted by RIVER2D at the upstream end of the site were compared to the WSELs predicted by PHABSIM at the top transect. In this study, where the highest simulated flow was much greater than the highest flow at which WSELs were measured, we initially tried to calibrate River2D using the WSELs simulated by PHABSIM, since we felt that any inaccuracies in the PHABSIM simulated WSELs were more than countered by the increased accuracy of calibrating the 2-D model at the highest flow to be simulated. The bed roughnesses of the computational mesh elements were then modified by multiplying them by a constant bed roughness multiplier (BR Mult)[15] until the WSELs predicted by RIVER2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the top transect. In cases where we were not able to calibrate River2D at the highest simulation flow, we instead calibrated using the WSEL measured at the highest flow (Appendix D). We concluded in these cases that the PHABSIM extrapolation of the WSELs, beyond the range of measured WSELs, at the upstream transect was inaccurate, and thus it was better to calibrate River2D to the highest measured WSEL.

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[15] We limited the range of BR Mult values to 0.3 to 3.0. This range was based on the range of bed roughnesses that would reasonably be expected in streams (Peter Steffler, personal communication). The value of the WSEL at the upstream transect generally increases with larger BR Mult values.

A stable solution will generally have a solution change (Sol Δ) of less than 0.00001 and a net flow (Net Q) of less than 1% (Steffler and Blackburn 2001). In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than one[16]. Finally, the WSEL predicted by the 2-D model should be within 0.10 foot (0.031 m) of the WSEL measured at the upstream transect[17]. The calibrated cdg files all had a solution change of less than 0.00001, with the net Q for all sites, except for Pre-restoration Site 3 and Post-restoration Site 3, less than 1% (Appendix D). We considered Pre-restoration Site 3 and Post-restoration Site 3 to still have a stable solution since the net Q was not changing and the net Q was still less than 2%. The calibrated cdg files for Pre-restoration Sites 1 and 3 and Post-restoration Sites 1 and 2 had a maximum Froude Number of greater than one (Appendix D). Pre-restoration Sites 1 and 3 and Post-restoration Site 1 included high-gradient riffles which would be expected to have supercritical flow, and thus Froude numbers greater than one. Pre-restoration Site 1 also had shallow smooth bedrock outcroppings near the middle of the channel, which would be expected to generate supercritical flows. In addition, we considered the solutions for all four sites to be acceptable since the Froude Number was only greater than one at a few nodes, with the vast majority of the site having Froude Numbers less than one. Furthermore, these nodes were located either at water's edge or where water depth was extremely shallow, typically approaching zero. A high Froude Number at a very limited number of nodes at water's edge or in very shallow depths would be expected to have a insignificant effect on the model results.

Initial attempts at calibrating Pre-restoration Sites 1 and 3 and Post-restoration Sites 1, 2 and 4 resulted in a significant over-prediction of the WSEL at the upstream transect, even using a BR Mult of 0.3. We concluded in these cases that PHABSIM was underpredicting the upstream transect WSEL at the highest simulation flow due to errors associated with extrapolating beyond the range of measured WSELs. As a result, we then switched to calibrating these sites at the highest measured flow (Appendix D). Even at the highest measured flow, River2D was still overestimating the WSEL at the upstream transect for these sites. We then tried different ways of putting breaklines through the portion of the sites that appeared to be responsible for the overprediction; these efforts were unsuccessful. We also tried lowering the bed elevation of these portions of the sites by 0.1 foot, so that the bed elevations were still within 0.1 foot of the measured bed elevations. This helped to reduce the WSEL at the upstream transect for Pre-restoration Sites 1 and 3 and Post-restoration Sites 1 and 2, and so we used these modified bed files for these sites. We had measured WSEL profiles going up through the sites for the post-restoration sites at a slightly lower flow than the highest flow that we measured WSELs at the upstream transect. At these flows (922 cfs for Site 1, 840 cfs for Site 2 and 742 cfs for Site 4), the

[16] This criteria is based on the assumption that flow in low gradient streams is usually subcritical, where the Froude number is less than one (Peter Steffler, personal communication).

[17] We have selected this standard because it is a standard used for PHABSIM (U. S. Fish and Wildlife Service 2000).

WSELs predicted by River2D at the upstream transect were within 0.1 foot of the measured WSEL at these flows for all of the Site 2 and 4 upstream transects and for a portion of the Site 1 upstream transect. As a result, we conclude that River2D was able to accurately simulate WSELs at lower flows for these sites, but overpredicted WSELs, and thus overpredicted depths and underpredicted velocities, for higher flows. We conclude that River2D's overprediction of WSELs at the upstream transects for Pre-restoration Sites 1 and 3 and Post-restoration Site 1 (Appendix D) were due to supercritical flow in the high-gradient riffle in these sites. High vertical accelerations, associated with high vertical curvature of the bed topography at the crest of supercritical riffles, can result in two-dimensional models overpredicting depths by up to 20%, since two-dimensional models cannot take vertical accelerations into account (Peter Steffler, personal communication). Alternatively, the overpredictions of WSELs could be due to some aspect of the bed topography of these sites that we did not capture in our data collection. For Post-restoration Site 3, the WSELs predicted by River2D on the banks of the upstream transect, where WSELs were measured, was within 0.1 foot of the PHABSIM-simulated WSEL, even though the WSELs in mid-channel were slightly higher. We concluded that the calibration in this case was sufficiently accurate, since the WSELs in mid-channel, could we have measured them, would have been slightly higher than the WSELs on the banks. Based on the above, we conclude that the River2D calibration of all of the sites was acceptable.

Velocity validation is the final step in the preparation of the hydraulic models for use in habitat simulation. Velocities predicted by RIVER2D were compared with measured velocities to determine the accuracy of the model's predictions of mean water column velocities. The measured velocities used were both those measured at the upper and lower transects and the 50 measurements taken between the transacts. See Appendix E for velocity validation statistics. Overall, the performance of River2D in predicting velocities was better for the post-restoration sites than for the pre-restoration sites, likely due to the less complex topography of the post-restoration sites. Although there was a strong correlation between predicted and measured velocities, there were significant differences between individual measured and predicted velocities. In general, the simulated and measured cross-channel velocity profiles at the upper and lower transects (Appendix E[18]) were relatively similar in shape. Differences in magnitude in most cases are likely due to (1) aspects of the bed topography of the site that were not captured in our data collection, (2) the effect of the velocity distribution at the upstream boundary of the site, (3) operator error during data collection, i.e., the probe was not facing precisely into the direction of current, and (4) range of natural velocity variation at each point over time resulting in some measured data points at the low or high end of the velocity range averaged in the model simulations. River2D distributes velocities across the upstream boundary in proportion to depth, so that the fastest velocities are at the thalweg. In contrast, the bed topography of a site may be such that the fastest measured velocities may be located in a different part of the channel. Since we did not measure the bed

[18] Velocities were plotted versus easting for transects that were orientated primarily east-west, while velocities were plotted versus northing for transects that were orientated primarily north-south.

topography upstream of a site, this may result in River2D improperly distributing the flow across the top of the site. As discussed above, we added artificial upstream extensions to the sites to try to address this issue. The 2-D model integrates effects from the surrounding elements at each point. Thus, point measurements of velocity can differ from simulated values simply due to the local area integration that takes place. As a result, the area integration effect noted above will produce somewhat smoother lateral cross-channel velocity profiles than the observations.

Overall, the simulated velocities for Pre-restoration Site 1 were relatively similar to the measured velocities for both transects, with some differences in magnitude that fall within the expected amount of natural variation in velocity. One measured velocity toward the west side of transect 2 that was lower than the simulated velocity can be attributed to a bed feature that likely existed upstream of the study site that slowed the water velocity. The simulated velocity accordingly reflected the absence of this feature. Overall, the simulated velocities for transect 2 were somewhat lower than the measured velocities. This was likely due to an overprediction of the water surface elevation at this transect resulting in deeper than measured depths and thus lower than measured velocities.

In Pre-restoration Site 2, the simulated and measured velocities matched poorly for both transects, particularly for the higher measured velocities. For transect 1, River2D overpredicted velocities on the west side of the channel and generally underpredicted velocities on the east side of the channel. We attribute this primarily to the bed topography downstream of the site, particularly a constriction on the west side of the channel that forced most of the flow towards the east side of the channel. Because this feature was outside of the site and not included in the model, the simulated velocities reflect a lack of any slowing influence on the west side of the channel. In addition, there were several small side channels on the east side of transect 1; the continuation of these side channels upstream of the transect was not well-represented in the bed topography, resulting in an underprediction of velocities in the side channels and an overprediction of velocities between the side channels and between the center side channel and the main channel. For transect 2, the difference between measured and simulated velocities can be attributed to high points upstream of the site which routed flow to the middle of the channel and blocked flow on either side of the middle of the channel. Again, since these features were outside of the site and not included in the model, the simulated velocities in this area could not reproduce the measured velocities.

For both of the transects in Pre-restoration Site 3, simulated velocities were greater than measured velocities on the east side of the channel and lower on the west side of the channel. We attribute this to the bed topography upstream of the site resulting in flow being forced to the east side of the channel, even though the depths on the east side were shallower than on the west side. Since this was a relatively short site with a high gradient, this effect carried through all the way to transect 1. Since the bed topography upstream of the site was not included in the model, River2D was unable to correctly distribute flows across the channel.

Simulated velocities were higher than measured velocities on the west side of Pre-restoration Site 4 transect 2 and lower than measured velocities on the east side of this transect. We attribute this to the bed topography upstream of transect 2 which resulted in most of the flow being forced to the east side of the channel, and to erroneously low measured velocities for the remainder of the transect (as evidenced by the erroneously low measured discharge for this transect). Again, since the bed topography upstream of the site was not included in the model, River2D was unable to replicate the observed pattern of velocities at this transect. The high velocities on the east side of transect 2 were distributed across the channel and shifted towards the middle of the channel as flows passed through the site, resulting in the measured velocity profile for transect 1. Since River2D did not have the correct distribution of velocities at the top of the site, it was similarly unable to reproduce the flow distribution at the bottom of the site.

Overall, the simulated velocities for Post-restoration Sites 1 and 3 were relatively similar to the measured velocities for all transects, with some differences in magnitude that fall within the expected amount of natural variation in velocity. The smoother simulated lateral velocity profile, as compared to the measured velocities, can be attributed to the area integration effect of River2D.

While the simulated and measured velocities were similar for the lower transect of Post-restoration Site 2, River2d overpredicted velocities on the north side and underpredicted velocities on the south side of transect 2. We attribute this to the bed topography upstream of the study site which resulted in higher than predicted velocities on the shallow south side of the transect and lower than predicted velocities on the deep north side of the transect. Since the bed topography upstream of the site was not included in the model, River2D was unable to correctly reproduce the velocity profile at the top of the site.

With the exception of the south side of transect 1, the simulated velocities for Post-restoration Site 4 were relatively similar to the measured velocities for both transects, with some differences in magnitude that fall within the expected amount of natural variation in velocity. The smoother simulated lateral velocity profile, as compared to the measured velocities, can be attributed to the area integration effect of River2D. The performance of the 2-D model at the lower transect was due to the model setting up a small eddy which was not present in the measured velocities. The use of a higher eddy viscosity coefficient could have eliminated this eddy, but was not thought necessary due to the small effect of this eddy on the overall habitat calculations, since it occupied a very small portion of the study site.

The flow and downstream WSEL in the calibrated cdg file were changed to simulate the hydraulics of the sites at the simulation flows (100 cfs to 2900 cfs by 100 cfs increments for the pre-restoration sites and 100 cfs to 2600 cfs by 100 cfs increments for the post-restoration sites[19]). The cdg file for each

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[19] The upper end of the simulated flows was selected as 2.5 times the flow at the highest measured WSELs (1162 cfs for the pre-restoration sites and 1047 cfs for the post-restoration sites).

flow contained the WSEL predicted by PHABSIM at the downstream transect at that flow. Each cdg file was run in RIVER2D to steady state. Again, a stable solution will generally have a Sol Δ of less than 0.00001 and a Net Q of less than 1%. In addition, solutions should usually have a Max F of less than one. The production cdg files all had a solution change of less than 0.00001, but the net Q was greater than 1% for all but two of the flows for Pre-restoration Site 3, and one flow for Post-restoration Site 1 (Appendix F). We still considered these sites to have a stable solution since net Q did not change and was less than 5%, with the exception of five flows for Pre-Restoration Site 3 (maximum of 6.2%). In comparison, the accepted level of accuracy for USGS gages is generally 5%. Thus, the difference between the flows at the upstream and downstream boundary (net Q) is within the same range as the accuracy for USGS gages, and is considered acceptable. The maximum Froude Number was greater than one for all of the simulated flows for Pre-restoration Site 1 and Post-restoration Site 1, 12 out of 29 simulated flows for Pre-restoration Site 2, 21 out of 23 simulated flows for Pre-restoration Site 3, 2 out of 29 simulated flows for Pre-restoration Site 4, 18 out of 26 simulated flows for Post-restoration Site 2, 1 out of 26 simulated flows for Post-restoration Site 3, and 9 out of 26 simulated flows for Post-restoration Site 4 (Appendix F); however, we considered these production runs to be acceptable since the Froude Number was only greater than one at a few nodes, with the vast majority of the area within the sites having Froude Numbers less than one. Also, as described previously, these nodes were located either at water's edge or where water depth was extremely shallow, typically approaching zero and would be expected to have an insignificant effect on the model results. Finally, Froude Numbers greater than one would be expected in the supercritical flow areas in the high-gradient riffle portions of Pre-restoration Sites 1 and 3 and Post-restoration Site 1 and the shallow smooth bedrock outcroppings near the middle of the channel of Pre-restoration Site 1.

Habitat Suitability Criteria (HSC) Development

The HSC for fall-run Chinook salmon spawning used in this study (Appendix G) were developed from Merced River fall-run Chinook salmon redd data (U.S. Fish and Wildlife Service 1997, Gard 1998). The HSC for fall-run Chinook salmon fry and juvenile rearing used in this study (Appendix G) were those developed from Sacramento River fry and juvenile fall-run Chinook salmon data (U.S. Fish and Wildlife Service 2005).

Biological Validation

We compared the combined habitat suitability predicted by RIVER2D at each redd location and at each young-of-the-year location in the pre- and post-restoration sites. For spawning, we ran the RIVER2D cdg files at 391 cfs (the average flow for the period Oct 30 - Nov 13, 2000) for the pre-restoration sites and at 205 cfs (the average flow for the period Oct 30 - Dec 3, 2002) for the post-restoration sites to determine the combined habitat suitability at individual points for RIVER2D. For fry and juvenile rearing, we ran the RIVER2D cdg files at 248 cfs (the flow on Jan 31 - Feb 1 and Mar

19-20, 2001) for the pre-restoration sites and at 222 and 577-665 cfs[20] (the flows on, respectively, Mar 11 and Apr 21-22, 2003) for the post-restoration sites to determine the combined habitat suitability at individual points for RIVER2D. We used the horizontal location measured for each redd or young-of-the-year to determine the location of each redd or young-of-the-year in the RIVER2D sites. We used a random number generator to select 200 locations without redds or young-of-the-year in each site. Locations were eliminated that: 1) were less than 3 feet from a previously-selected location; 2) were less than 3 feet from a redd or young-of-the-year location; 3) were not located in the wetted part of the site; and 4) were located in the site, rather than in the upstream extension of the file. We used Mann-Whitney U tests (Zar 1984) to determine whether the compound suitability predicted by RIVER2D was higher at redd or young-of-the-year locations versus locations where redds or young-of-the year were absent.

Habitat Simulation

The final step was to simulate available habitat for each site for fall-run Chinook salmon spawning and fry and juvenile rearing. Preference curve files for spawning and rearing were created containing the digitized HSC developed for Merced River fall-run Chinook salmon spawning and Sacramento River fall-run Chinook salmon fry and juvenile rearing (Appendix G). RIVER2D was used with the final cdg files, the substrate file and the preference curve file to compute spawning WUA (weighted useable area) for each habitat unit in each site over the desired range of flows (100 cfs to 2900 cfs by 100 cfs increments for the pre-restoration sites and 100 cfs to 2600 cfs by 100 cfs increments for the post-restoration sites). This process was repeated to compute the fry and juvenile rearing WUA using RIVER2D with the final cdg files, the cover file and the fry and juvenile rearing preference files. The fall-run Chinook salmon adult spawning and fry and juvenile rearing WUA values calculated for each site are contained in Appendix H. The WUA values for all of the habitat units of a given habitat type for all of the pre-restoration sites were added together for each habitat type. The resulting total for each habitat type was then multiplied by the ratio of the length of each habitat type in the reach divided by the length of each habitat type in the sites (in Table 5) to estimate the WUA for each habitat type in the entire restoration reach. The resulting WUAs were added together to generate the total WUA for the entire pre-restoration reach (Appendix H). The same process was conducted for the post-restoration sites and post-restoration habitat type lengths in Table 5 to generate the total WUA for the entire post-restoration reach (Appendix H).

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[20] We used 665 cfs (the flow on Apr 21) for Sites 2-4, since we sampled those sites on that date, and used 577 cfs (the flow on Apr 22) for Site 1, since we sampled that site on that date.

RESULTS

Biological Validation

The combined habitat suitability predicted by the 2-D model was significantly higher for locations with redds (median = 0.12, n = 48) than for locations without redds (median = 0, n = 1600), based on the Mann-Whitney U test ($p < 0.000001$). The frequency distribution of combined habitat suitability for locations with redds is shown in Figure 1, while the frequency distribution of combined habitat suitability for locations without redds is shown in Figure 2. The location of redds relative to the distribution of combined suitability is shown in Appendix I. Of the six redd locations that the 2-D model predicted had a combined suitability of zero (12%), four had a combined suitability of zero due to the predicted substrate being too large (substrate codes 4.6, 6.8, 8, 9 and 10), and two had a combined suitability of zero because the velocity was too slow (less than 0.4 ft/s).

Figure 1
Combined Suitability for 2-D Model Locations With Redds

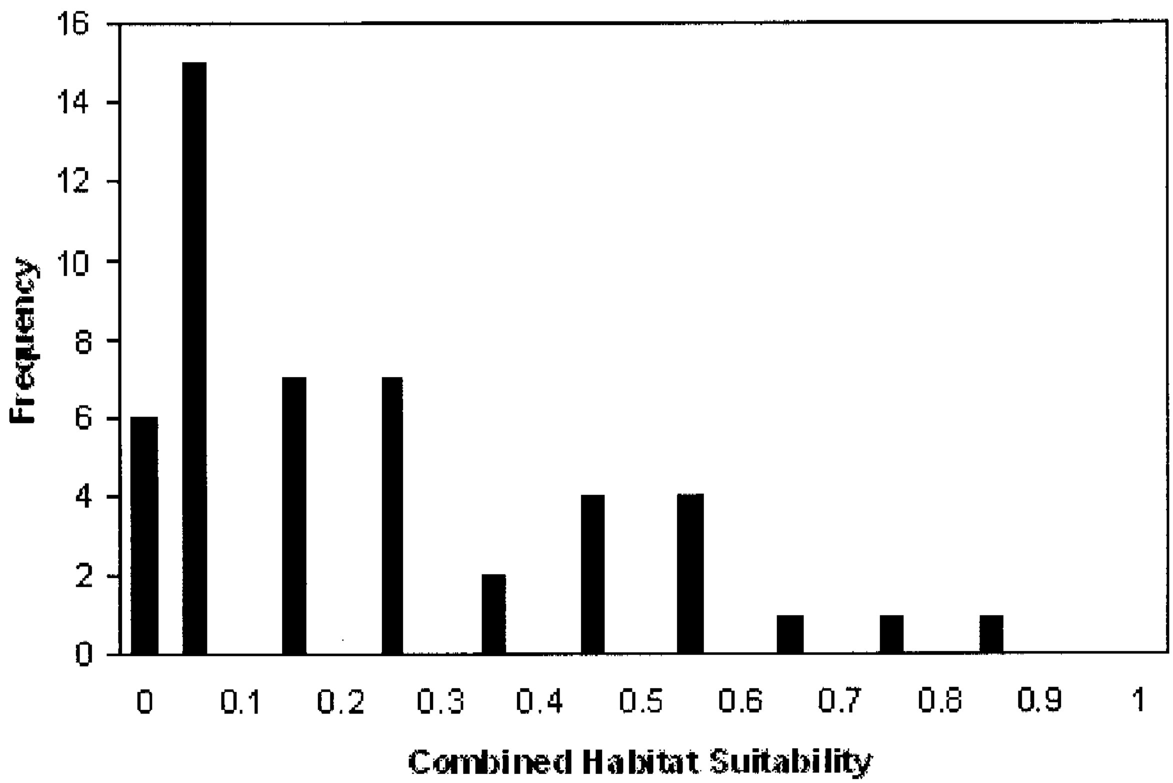
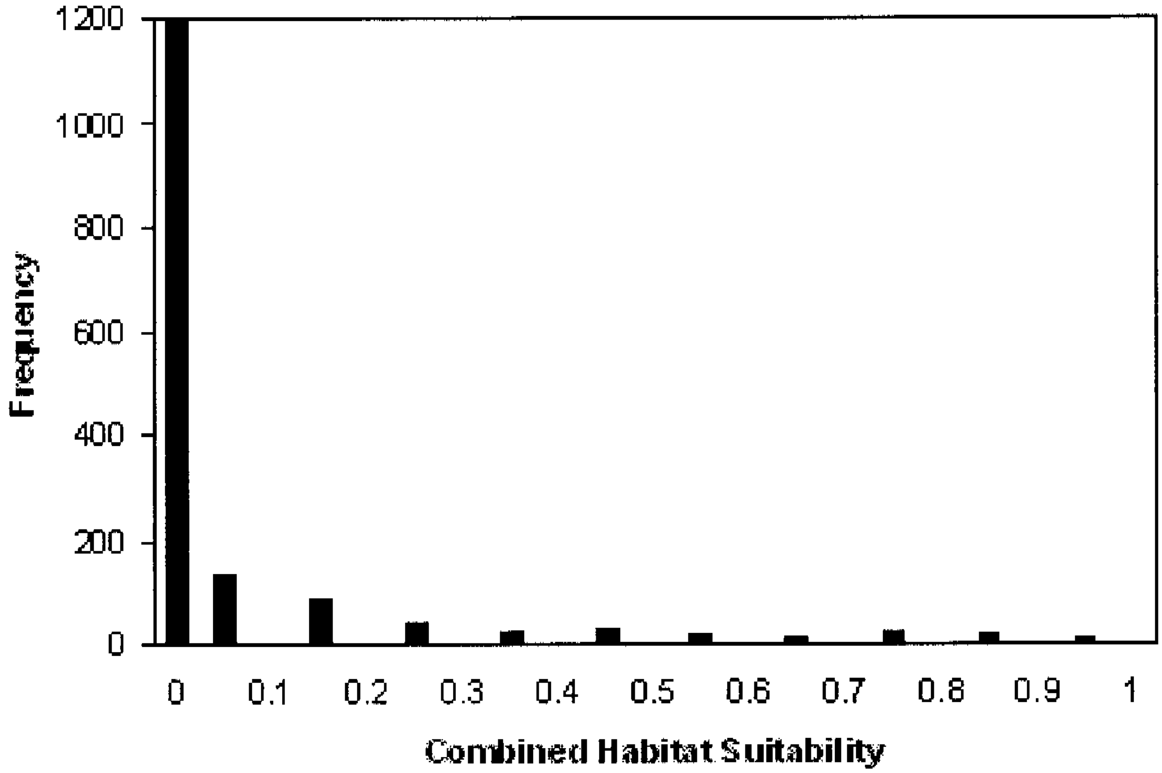


Figure 2
Combined Suitability for 2-D Model Locations Without Redds



The combined habitat suitability predicted by the 2-D model was significantly higher for locations with fry (median = 0.12, n = 71) than for locations without fry (median = 0.06, n = 2400), based on the Mann-Whitney U test (p = 0.000001). The frequency distribution of combined habitat suitability for locations with fry is shown in Figure 3, while the frequency distribution of combined habitat suitability for locations without fry is shown in Figure 4. The location of fry relative to the distribution of combined suitability is shown in Appendix I. Of the 14 fry locations that the 2-D model predicted had a combined suitability of zero (20%), all had a combined suitability of zero due to River2D predicting that their location would be dry.

The combined habitat suitability predicted by the 2-D model was significantly higher for locations with juveniles (median = 0.014, n = 13) than for locations without juveniles (median = 0.008, n = 1600), based on the Mann-Whitney U test (p = 0.012). The frequency distribution of combined habitat suitability for locations with juveniles is shown in Figure 5, while the frequency distribution of combined habitat suitability for locations without juveniles is shown in Figure 6. The 2-D model did not predict that any of the juvenile locations would have a combined suitability of zero.

Figure 3
Combined Suitability for 2-D Model Locations With Fry

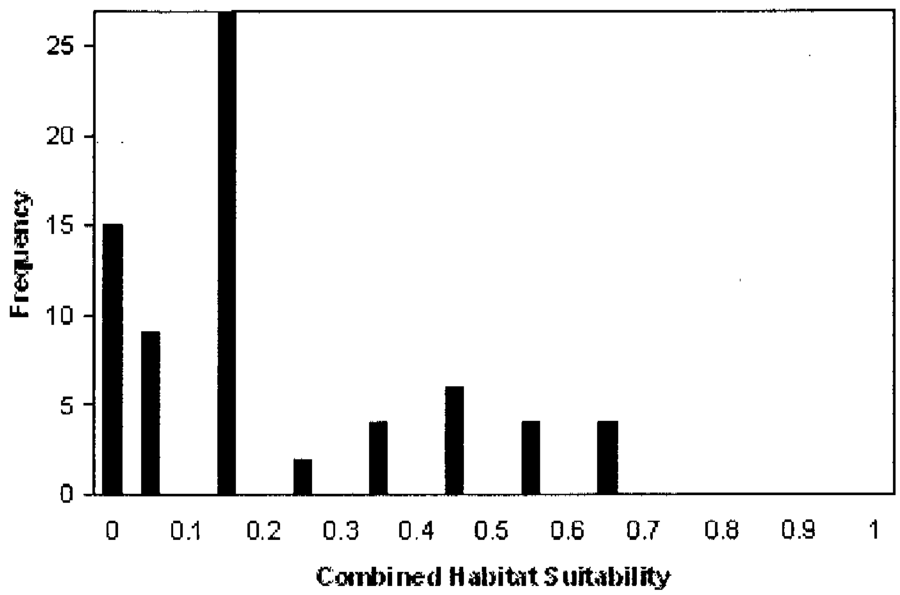


Figure 4
Combined Suitability for 2-D Model Locations Without Fry

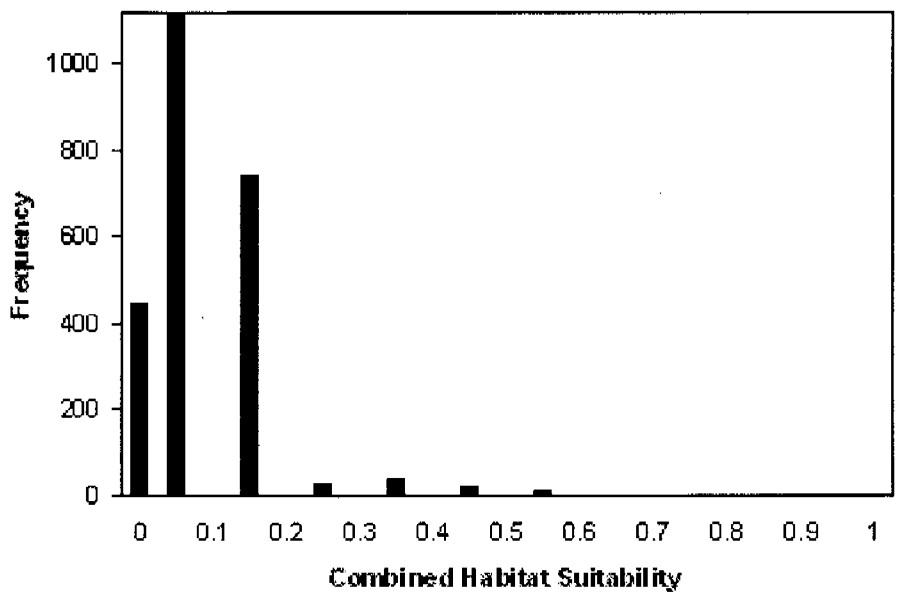


Figure 5
Combined Suitability for 2-D Model Locations With Juveniles

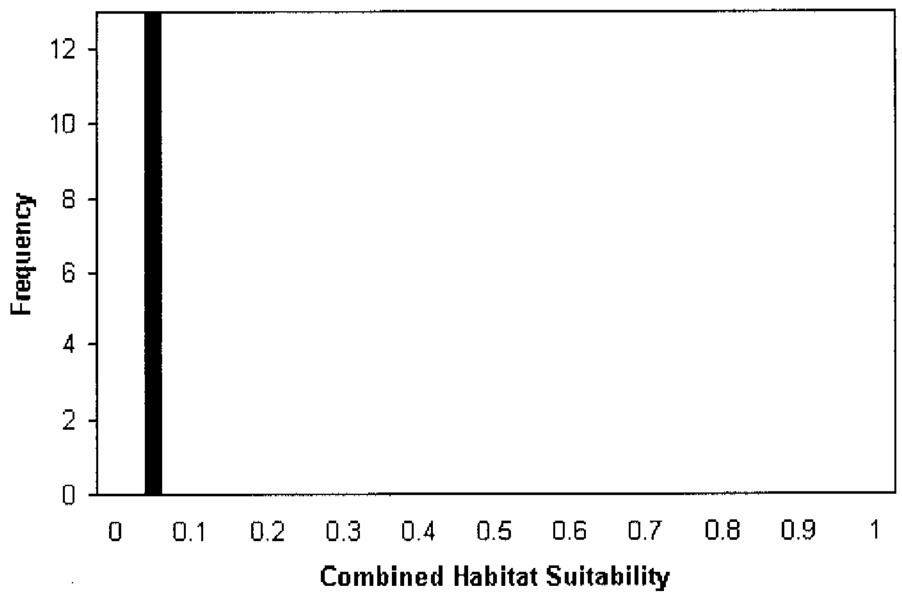
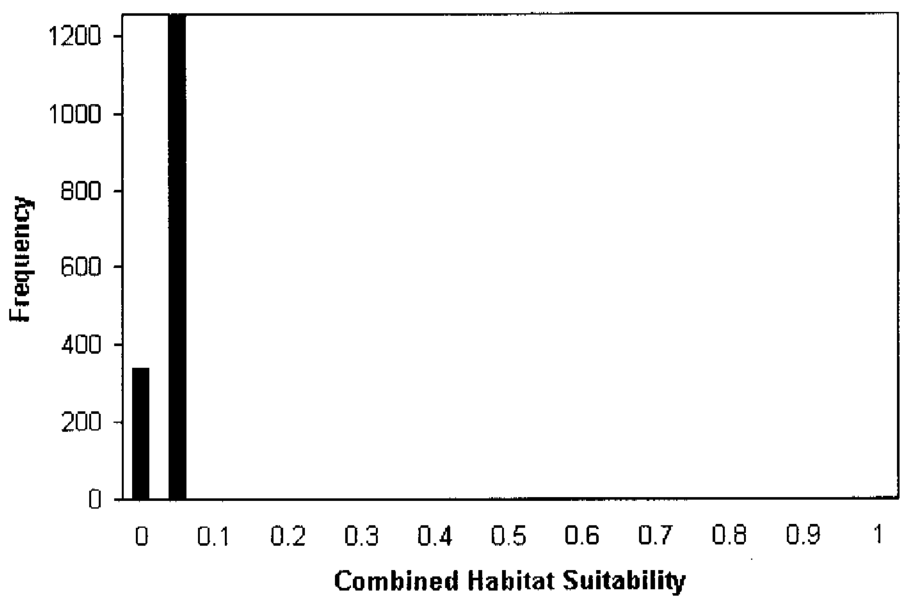


Figure 6
Combined Suitability for 2-D Model Locations Without Juveniles



Habitat Simulation

As shown in Figure 7, there was a increase in the amount of spawning habitat associated with the restoration at flows below 450 cfs, but a decrease in spawning habitat at flows above 450 cfs. There was a decrease in the amount of fry (Figure 8) and juvenile (Figure 9) rearing habitat associated with the restoration.

DISCUSSION

If fall flows are kept under 450 cfs, the restoration project will result in an increase in spawning habitat for fall-run Chinook salmon. Differences in the spawning flow-habitat relationships for the Merced River prior to the 1997 flood (data from U.S. Fish and Wildlife Service 1997) and for the post-restoration reach will complicate efforts to manage Merced River flows. While it would maximize the spawning habitat in the post-restoration reach to have fall flows of 100 cfs, this action would reduce the amount of spawning habitat in the remainder of the Merced River below what could be achieved at a fall flow of 350 cfs, assuming that the spawning flow-habitat relationship in the remainder of the Merced River was not changed by the 1997 flood (Figure 10). The shape of the spawning flow-habitat relationship for the post-restoration reach appears to be due to velocities being higher than optimal in riffles and runs for spawning, as a result of the gradient of the site. One potential solution would be to install one or two high-gradient riffles, so that the water surface gradient of the remaining riffles and runs would be reduced.

A substantial portion of the fry and juvenile rearing habitat in the pre-restoration site was in side channel habitats, with slower velocities than in the main channel. With the simplified design of the restoration project, without any side channels, fry and juvenile habitat is restricted to a narrow band along both banks where velocities are slow enough for fry and juvenile rearing. The reduction in fry and juvenile rearing habitat with restoration can also be attributed to the lack of overhanging vegetation and large woody debris (cover codes 3.7, 4, 4.7, 5 and 5.7) in the channel; these cover elements result in a four-fold increase in habitat quality and thus in weighted useable area. Construction of side channel habitats and installation of large woody debris would help to ameliorate the decrease in fry and rearing habitat associated with the restoration project.

Figure 7
Results of Spawning Habitat Modeling

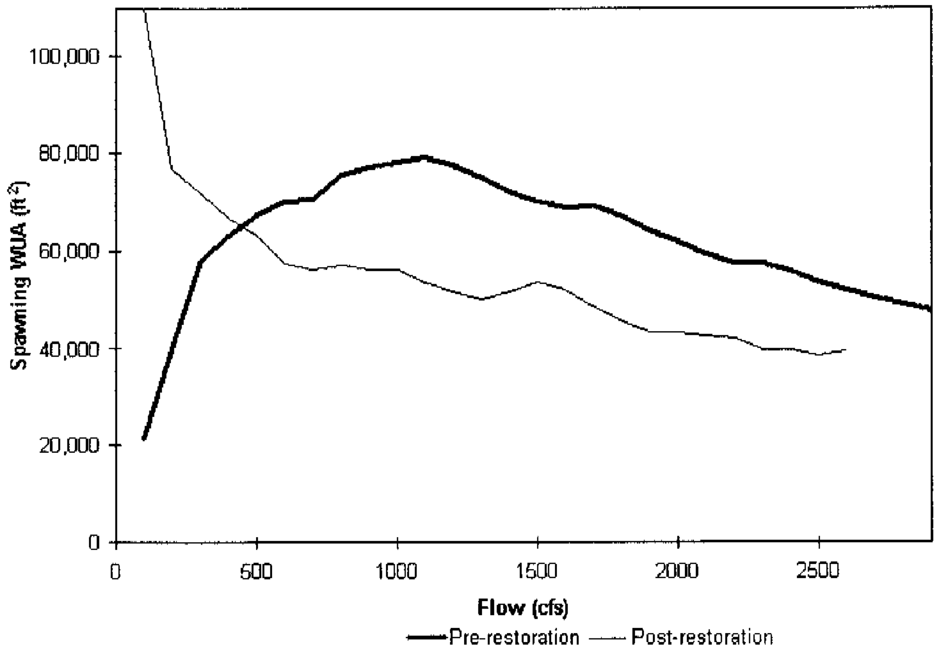


Figure 8
Results of Fry Habitat Modeling

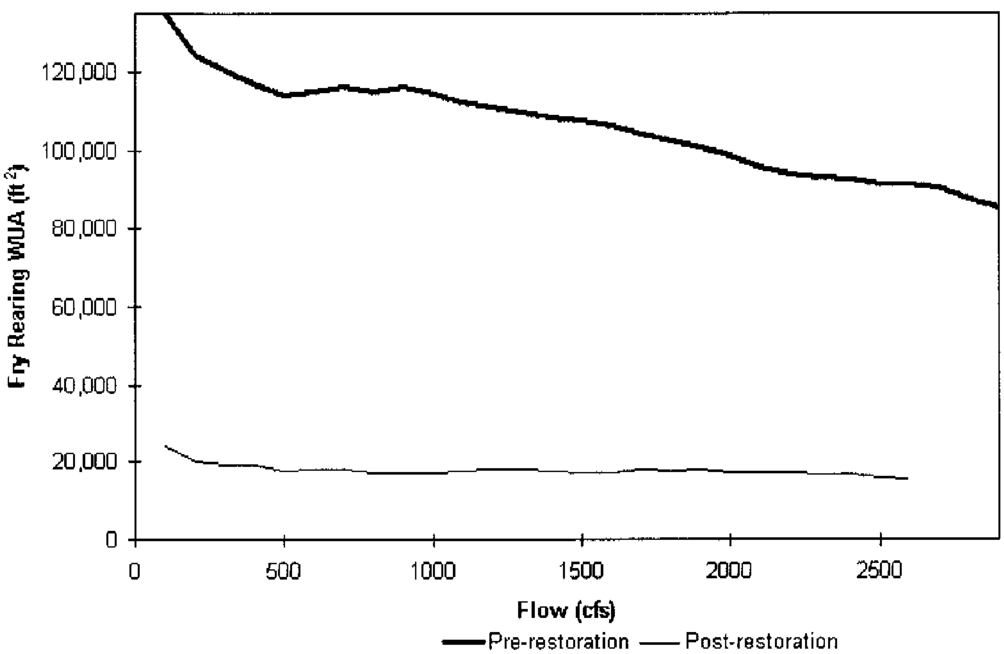


Figure 9
Results of Juvenile Habitat Modeling

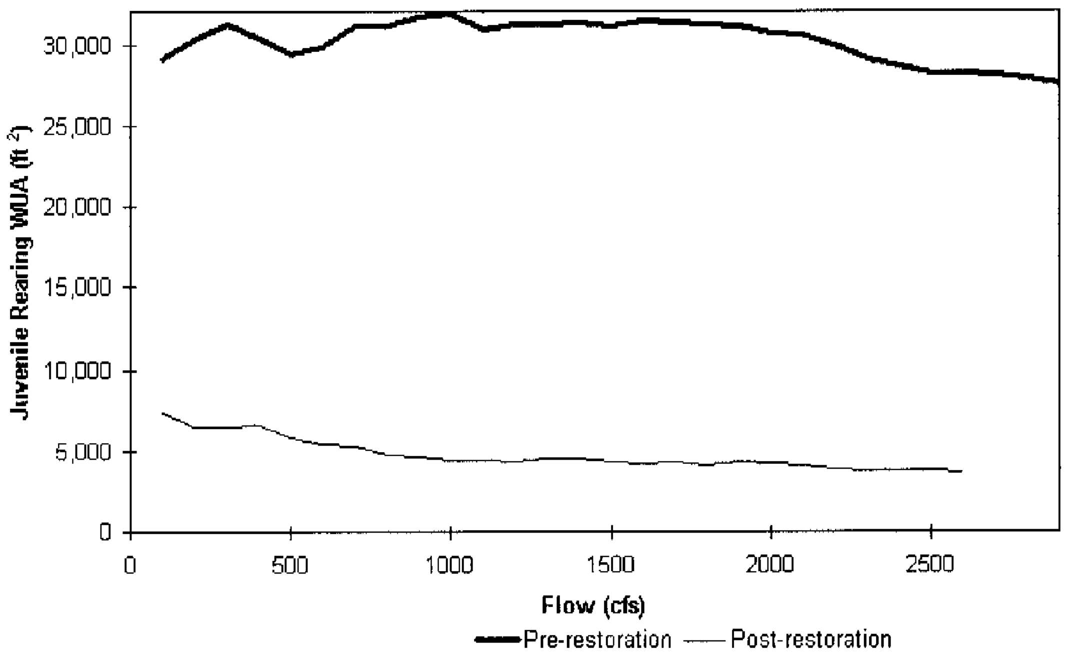
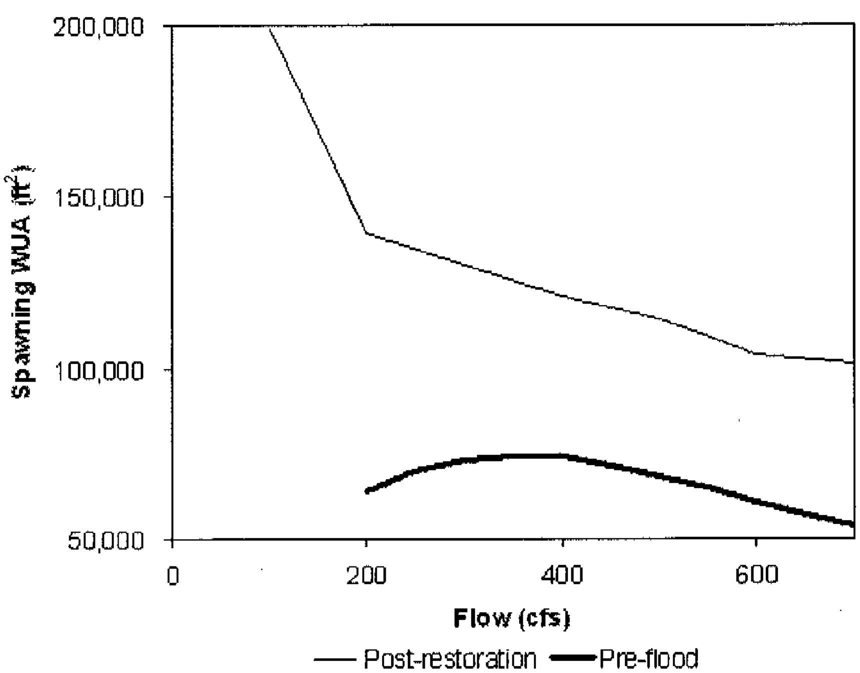


Figure 10
Comparison of Post-Restoration and Pre-1997 Flood Spawning Flow-Habitat Relationships



REFERENCES

Gard, M. 1998. Technique for adjusting spawning depth habitat utilization curves for availability. Rivers 6: 94-102.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1995. Two-dimensional modeling of flow in aquatic habitats. Water Resources Engineering Report 95-S1, Department of Civil Engineering, University of Alberta, Edmonton, Alberta. March 1995.

Milhous, R. T., M. A. Updike and D. M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U. S. Fish and Wildlife Service Biological Report 89(16).

Payne and Associates. 1998. RHABSIM 2.0 for DOS and Windows User's Manual. Arcata, CA: Thomas R. Payne and Associates.

Steffler, P. 2001a. R2D_Mesh - mesh generation program for River2D two dimensional depth averaged finite element hydrodynamic model - version 2.01. User's manual. University of Alberta, Edmonton, Alberta. 22 pp. http://bertram.civil.ualberta.ca/download.htm

Steffler, P. 2001b. River2D_Bed. Bed topography file editor - version 1.23. User's manual. University of Alberta, Edmonton, Alberta. 24 pp. http://bertram.civil.ualberta.ca/download.htm

Steffler, P. and J. Blackburn. 2001. River2D: Two-dimensional depth averaged model of river hydrodynamics and fish habitat. Introduction to depth averaged modeling and user's manual. University of Alberta, Edmonton, Alberta. 88 pp. http://bertram.civil.ualberta.ca/download.htm

U.S. Fish and Wildlife Service. 1994. Using the computer based physical habitat simulation system (PHABSIM). Fort Collins, CO: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. 1997. Identification of the instream flow requirements for fall-run Chinook salmon spawning in the Merced River. Sacramento, CA: U.S. Fish and Wildlife Service.

U. S. Fish and Wildlife Service. 2000. Effects of the January 1997 flood on flow-habitat relationships for steelhead and fall-run Chinook salmon spawning in the Lower American River. Sacramento, CA: U.S. Fish and Wildlife Service.

U. S. Fish and Wildlife Service. 2001. Merced River salmon habitat enhancement project and Robinson reach phase. Initial study/environmental assessment. Sacramento, CA: U.S. Fish and Wildlife Service.

U. S. Fish and Wildlife Service. 2005. Flow-habitat relationships for Chinook salmon rearing in the Sacramento River between Keswick Dam and Battle Creek. Sacramento, CA: U.S. Fish and Wildlife Service.

Yalin, M. S. 1977. Mechanics of Sediment Transport. New York: Pergamon Press.

Zar, J. H. 1984. Biostatistical Analysis, Second Edition. Englewood Cliffs, NJ: Prentice-Hall, Inc.

APPENDIX A
RHABSIM WSEL CALIBRATION

Calibration Methods and Parameters Used

Study Site	XS #	Flow Range	Calibration Flows	Method	Parameters
Pre-restoration					
Site 1	1, 2	100-2900	125, 452, 865, 1162	IFG4	---
Site 2	1	100-400	108, 472, 879	IFG4	---
Site 2	2	100-400	108, 472	WSP	n = 0.04, RM = 1
Site 2	1, 2	500-2900	472, 879, 1162	IFG4	---
Site 3	1	100-2900	146, 452, 879, 1162	MANSQ	β = 0.5, CALQ = 879
Site 3	2	100-2900	146, 452, 879, 1162	IFG4	---
Site 4	1, 2	100-800	108, 452, 879	IFG4	---
Site 4	1	900-2900	879, 1162	MANSQ	β = 0.5, CALQ = 1162
Site 4	2	900-2900	879, 1162	WSP	n = 0.04, RM = 1
Post-restoration					
Site 1	1	100-300	134, 198, 379	IFG4	---
Site 1	2	100-400	134, 198, 379, 468	IFG4	---
Site 1	1	400-2600	379, 468, 1047	IFG4	---
Site 1	2	500-2600	468, 1047	MANSQ	β = 0.5, CALQ = 1047
Site 2	1, 2	100-300	134, 198, 379	IFG4	---
Site 2	1, 2	400-2600	379, 468, 1047	IFG4	---
Site 3	1, 2	100-400	198, 379, 468	IFG4	---
Site 3	1	400-2600	468, 1047	MANSQ	β = 0.5, CALQ = 1047
Site 3	2	500-1000	468, 1047	MANSQ	β = 0.5, CALQ = 1047
Site 3	2	1100-2600	1047	WSP	XS2 WSEL = XS 1 WSEL
Site 4	1	100-300	134, 198, 379	IFG4	---
Site 4	2	100-400	198, 379, 468	IFG4	---
Site 4	1	400-2600	379, 468, 1047	IFG4	---
Site 4	2	500-2600	468, 1047	MANSQ	β = 0.5, CALQ = 1047

Pre-restoration

Site 1

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 125 cfs	452 cfs	865 cfs	1162 cfs	Difference (measured vs. pred. WSELs) 125 cfs	452 cfs	865 cfs	1162 cfs
1	2.93	3.6	1.5	2.7	4.4	5.9	0.01	0.03	0.06	0.08
2	3.74	4.1	2.2	6.4	5.9	2.1	0.01	0.04	0.05	0.02

Site 2

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 108 cfs	472 cfs	879 cfs	Difference (measured vs. pred. WSELs) 108 cfs	472 cfs	879 cfs
1	3.53	11.2	6.7	18.6	9.6	0.03	0.13	0.06

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 108 cfs	472 cfs	Difference (measured vs. pred. WSELs) 108 cfs	472 cfs
2	---	---	---	---	0.04	0.10

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 472 cfs	879 cfs	1162 cfs	Difference (measured vs. pred. WSELs) 472 cfs	879 cfs	1162 cfs
1	2.68	2.8	1.0	4.2	3.3	0.01	0.05	0.04
2	2.69	3.5	1.1	5.0	4.1	0.05	0.06	0.06

Site 3

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 146 cfs	452 cfs	879 cfs	1162 cfs	Difference (measured vs. pred. WSELs) 146 cfs	452 cfs	879 cfs	1162 cfs
1	---	6.3	9.3	7.1	0.0	8.6	0.04	0.05	0.00	0.06
2	2.93	3.7	2.3	5.0	2.3	5.3	0.01	0.03	0.02	0.05

Site 4

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 108 cfs	452 cfs	879 cfs	Difference (measured vs. pred. WSELs) 108 cfs	452 cfs	879 cfs
1	1.84	3.5	2.0	5.4	3.1	0.01	0.06	0.06
2	1.84	3.1	1.8	4.8	2.8	0.01	0.06	0.05

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 879 cfs	1162 cfs	Difference (measured vs. pred. WSELs) 879 cfs	1162 cfs
1	---	7.2	5.8	8.6	0.08	0.10
2	---	---	---	---	0.07	0.08

Post-restoration

Site 1

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 134 cfs	198 cfs	379 cfs	Difference (measured vs. pred. WSELs) 134 cfs	198 cfs	379 cfs
1	2.34	0.2	0.2	0.4	0.1	0.00	0.00	0.00

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 134	198 cfs	379 cfs	468 cfs	Difference (measured vs. pred. WSELs) 134 cfs	198 cfs	379 cfs	468 cfs
2	3.30	4.7	1.5	1.8	10.0	6.1	0.01	0.01	0.06	0.05

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 379 cfs	468 cfs	1047 cfs	Difference (measured vs. pred. WSELs) 379 cfs	468 cfs	1047 cfs
1	3.54	6.5	6.4	9.2	3.5	0.04	0.07	0.03

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 468 cfs	1047 cfs	Difference (measured vs. pred. WSELs) 468 cfs	1047 cfs
2	---	14.1	22.9	5.4	0.10	0.04

Site 2

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 134 cfs	198 cfs	379 cfs	Difference (measured vs. pred. WSELs) 134 cfs	198 cfs	379 cfs
1	2.00	1.6	1.5	2.4	0.8	0.01	0.02	0.01
2	2.36	1.9	1.9	2.9	0.9	0.01	0.02	0.01

XSEC	BETA COEFF.	%MEAN ERROR	Calculated vs Given Disch. (%) 379 cfs	468 cfs	1047 cfs	Difference (measured vs. pred. WSELs) 379 cfs	468 cfs	1047 cfs
1	3.41	5.1	5.3	7.3	2.5	0.04	0.07	0.03
2	3.20	6.3	6.3	8.9	3.3	0.05	0.08	0.04

Site 3

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	198 cfs	379 cfs	468 cfs	198 cfs	379 cfs	468 cfs
1	1.39	2.2	0.6	3.2	2.7	0.01	0.06	0.05
2	1.40	2.0	0.5	2.8	2.4	0.01	0.05	0.05

	BETA	%MEAN	Calculated vs Given Disch. (%)		Difference (measured vs. pred. WSELs)	
XSEC	COEFF.	ERROR	468 cfs	1047 cfs	468 cfs	1047 cfs
1	---	5.6	11.1	0.1	0.10	0.01
2	---	3.5	7.0	0.1	0.05	0.01

	BETA	%MEAN	Calculated vs Given Disch. (%)	Difference (measured vs. pred. WSELs)
XSEC	COEFF.	ERROR	1047 cfs	1047 cfs
2	---	---	---	0.00

Site 4

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	134 cfs	198 cfs	379 cfs	134 cfs	198 cfs	379 cfs
1	1.98	0.8	0.7	1.2	0.4	0.01	0.01	0.01

	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	198 cfs	379 cfs	468 cfs	198 cfs	379 cfs	468 cfs
2	2.19	1.4	0.4	2.1	1.7	0.00	0.03	0.03

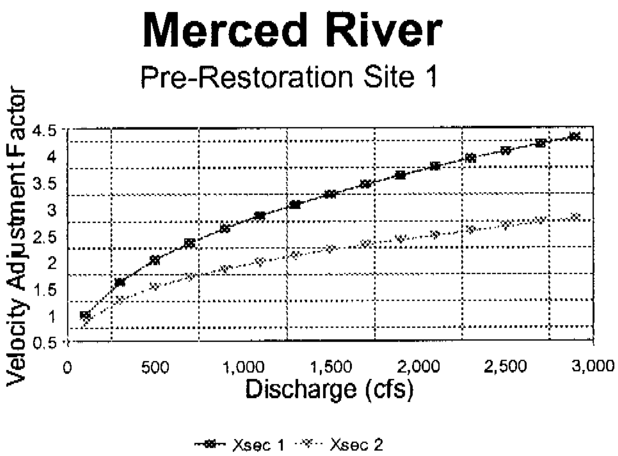
	BETA	%MEAN	Calculated vs Given Disch. (%)			Difference (measured vs. pred. WSELs)		
XSEC	COEFF.	ERROR	379 cfs	468 cfs	1047 cfs	379 cfs	468 cfs	1047 cfs
1	3.31	5.6	5.7	8.0	2.8	0.05	0.07	0.03

	BETA	%MEAN	Calculated vs Given Disch. (%)		Difference (measured vs. pred. WSELs)	
XSEC	COEFF.	ERROR	468 cfs	1047 cfs	468 cfs	1047 cfs
2	---	4.5	9.0	0.1	0.08	0.01

APPENDIX B
VELOCITY ADJUSTMENT FACTORS

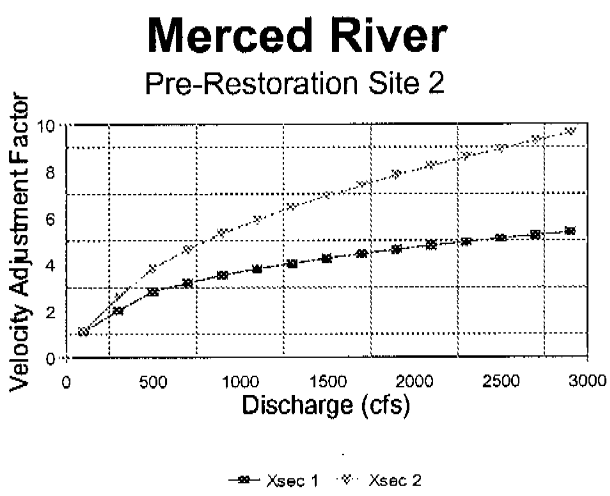
PRE-RESTORATION STUDY SITE 1

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
100	0.98	0.87
300	1.62	1.28
500	2.03	1.52
700	2.35	1.71
900	2.62	1.86
1100	2.85	1.99
1300	3.07	2.10
1500	3.26	2.21
1700	3.44	2.31
1900	3.61	2.40
2100	3.77	2.49
2300	3.92	2.57
2500	4.06	2.65
2700	4.20	2.72
2900	4.33	2.80



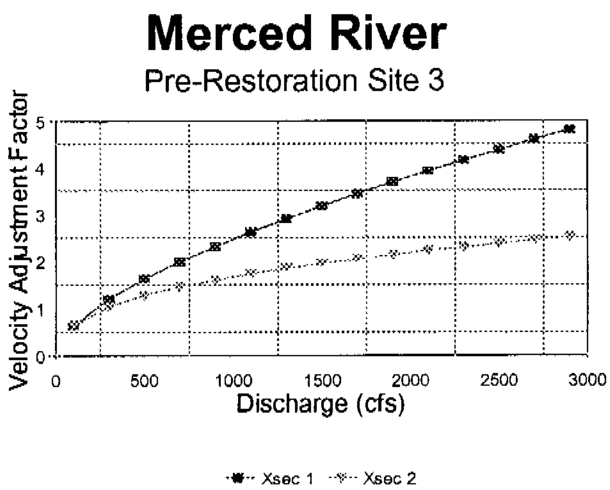
PRE-RESTORATION STUDY SITE 2

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
100	1.09	1.14
300	2.01	2.59
500	2.82	3.82
700	3.20	4.61
900	3.51	5.29
1100	3.78	5.89
1300	4.01	6.43
1500	4.23	6.92
1700	4.42	7.37
1900	4.60	7.80
2100	4.77	8.20
2300	4.93	8.58
2500	5.09	8.94
2700	5.23	9.28
2900	5.37	9.61



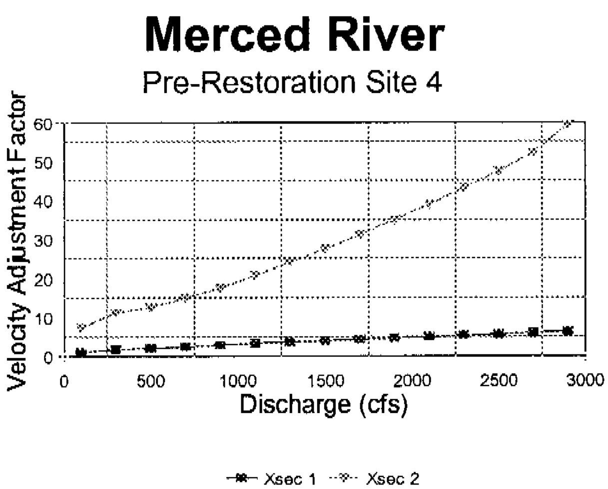
PRE-RESTORATION STUDY SITE 3

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
100	0.64	0.64
300	1.20	1.04
500	1.63	1.28
700	1.99	1.45
900	2.32	1.60
1100	2.62	1.73
1300	2.90	1.85
1500	3.17	1.95
1700	3.43	2.05
1900	3.68	2.14
2100	3.92	2.22
2300	4.15	2.30
2500	4.37	2.38
2700	4.59	2.45
2900	4.80	2.52



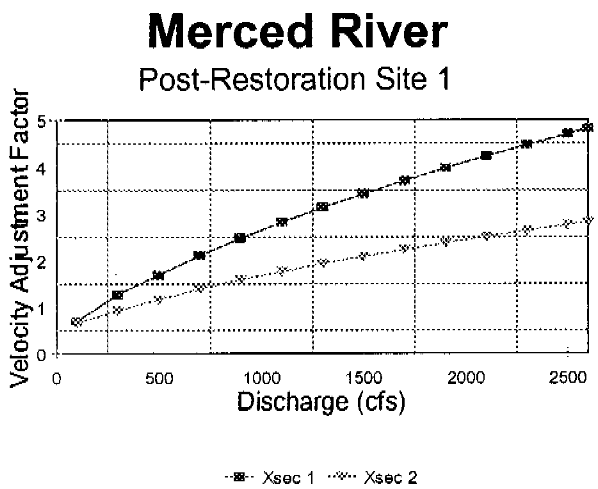
PRE-RESTORATION STUDY SITE 4

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
100	1.05	7.28
300	1.79	11.01
500	2.07	12.42
700	2.52	15.02
900	2.89	17.55
1100	3.27	20.63
1300	3.65	23.95
1500	4.02	27.47
1700	4.36	31.10
1900	4.69	34.89
2100	5.00	38.89
2300	5.32	43.05
2500	5.61	47.45
2700	5.90	52.09
2900	6.33	59.35



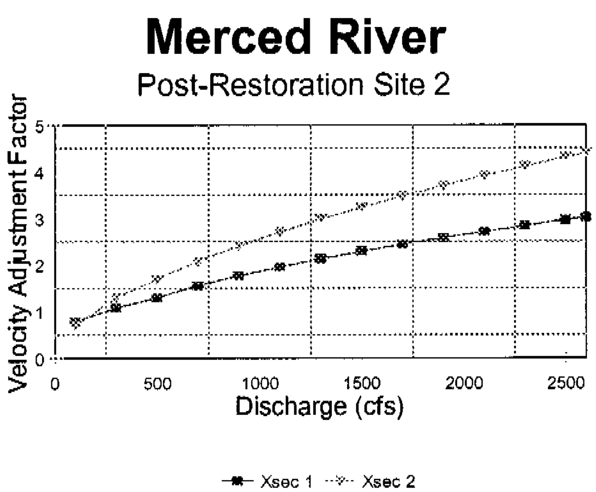
POST-RESTORATION STUDY SITE 1

Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
100	0.69	0.66
300	1.28	0.92
500	1.69	1.17
700	2.11	1.39
900	2.48	1.59
1100	2.82	1.77
1300	3.13	1.93
1500	3.43	2.09
1700	3.70	2.24
1900	3.97	2.37
2100	4.22	2.51
2300	4.47	2.64
2500	4.70	2.76
2600	4.82	2.82



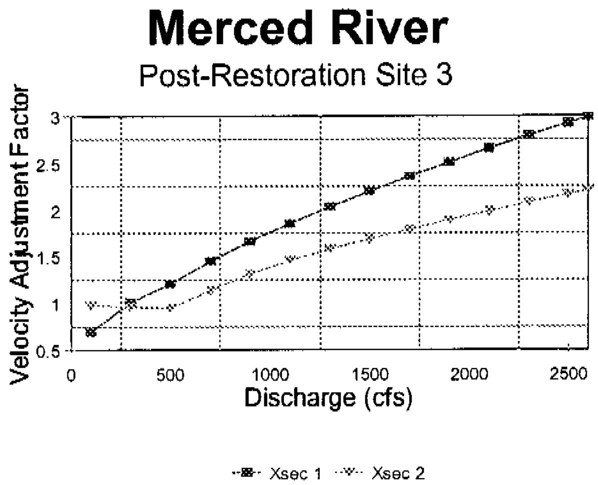
POST-RESTORATION STUDY SITE 2

Discharge	Velocity Adjustment Factors Xsec 1	Xsec 2
100	0.78	0.70
300	1.08	1.30
500	1.29	1.69
700	1.55	2.07
900	1.76	2.41
1100	1.95	2.71
1300	2.13	2.98
1500	2.29	3.24
1700	2.44	3.47
1900	2.58	3.70
2100	2.71	3.91
2300	2.84	4.11
2500	2.96	4.31
2600	3.02	4.40



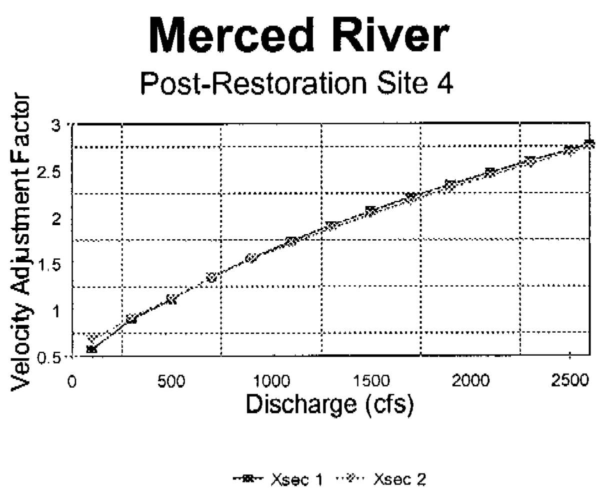
POST-RESTORATION STUDY SITE 3

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
100	0.69	0.98
300	1.01	0.96
500	1.21	0.95
700	1.45	1.14
900	1.66	1.32
1100	1.85	1.46
1300	2.03	1.58
1500	2.20	1.69
1700	2.36	1.79
1900	2.51	1.89
2100	2.65	1.99
2300	2.79	2.08
2500	2.92	2.16
2600	2.99	2.21



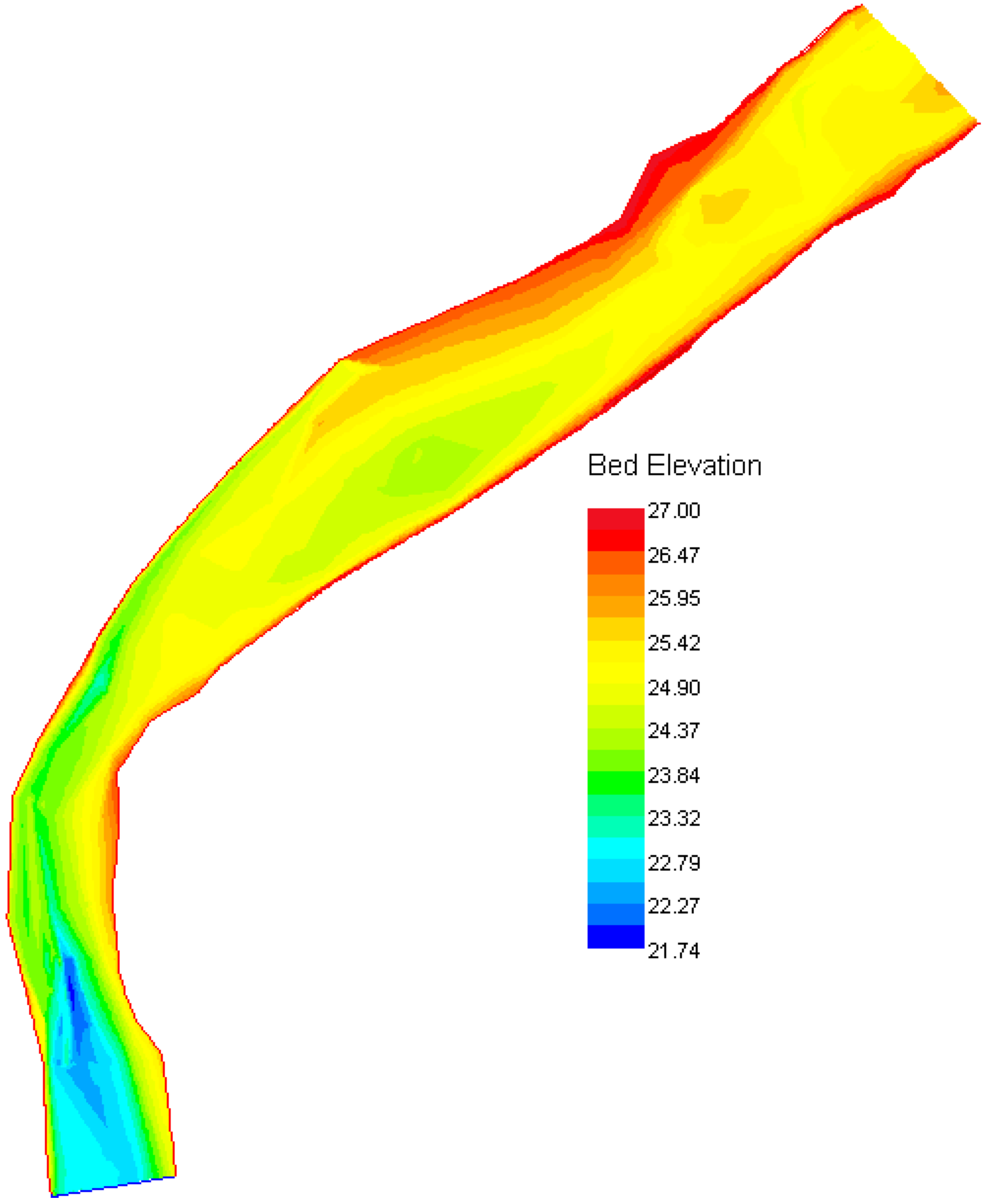
POST-RESTORATION STUDY SITE 4

	Velocity Adjustment Factors	
Discharge	Xsec 1	Xsec 2
100	0.58	0.68
300	0.90	0.92
500	1.11	1.13
700	1.35	1.35
900	1.55	1.54
1100	1.74	1.71
1300	1.91	1.87
1500	2.06	2.03
1700	2.21	2.17
1900	2.34	2.30
2100	2.47	2.44
2300	2.60	2.56
2500	2.71	2.68
2600	2.77	2.74



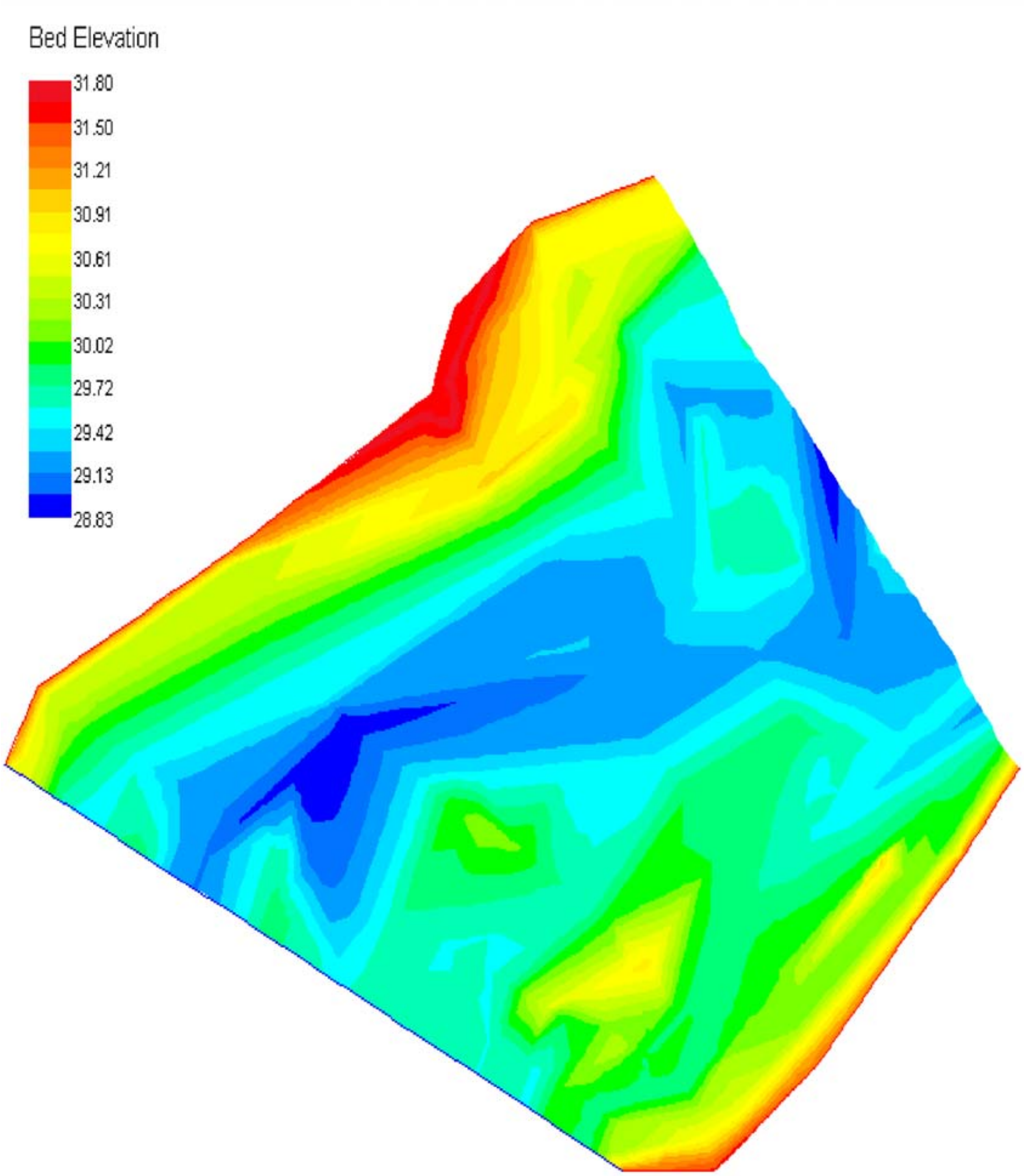
APPENDIX C
BED TOPOGRAPHY OF STUDY SITES

PRE-RESTORATION SITE 1



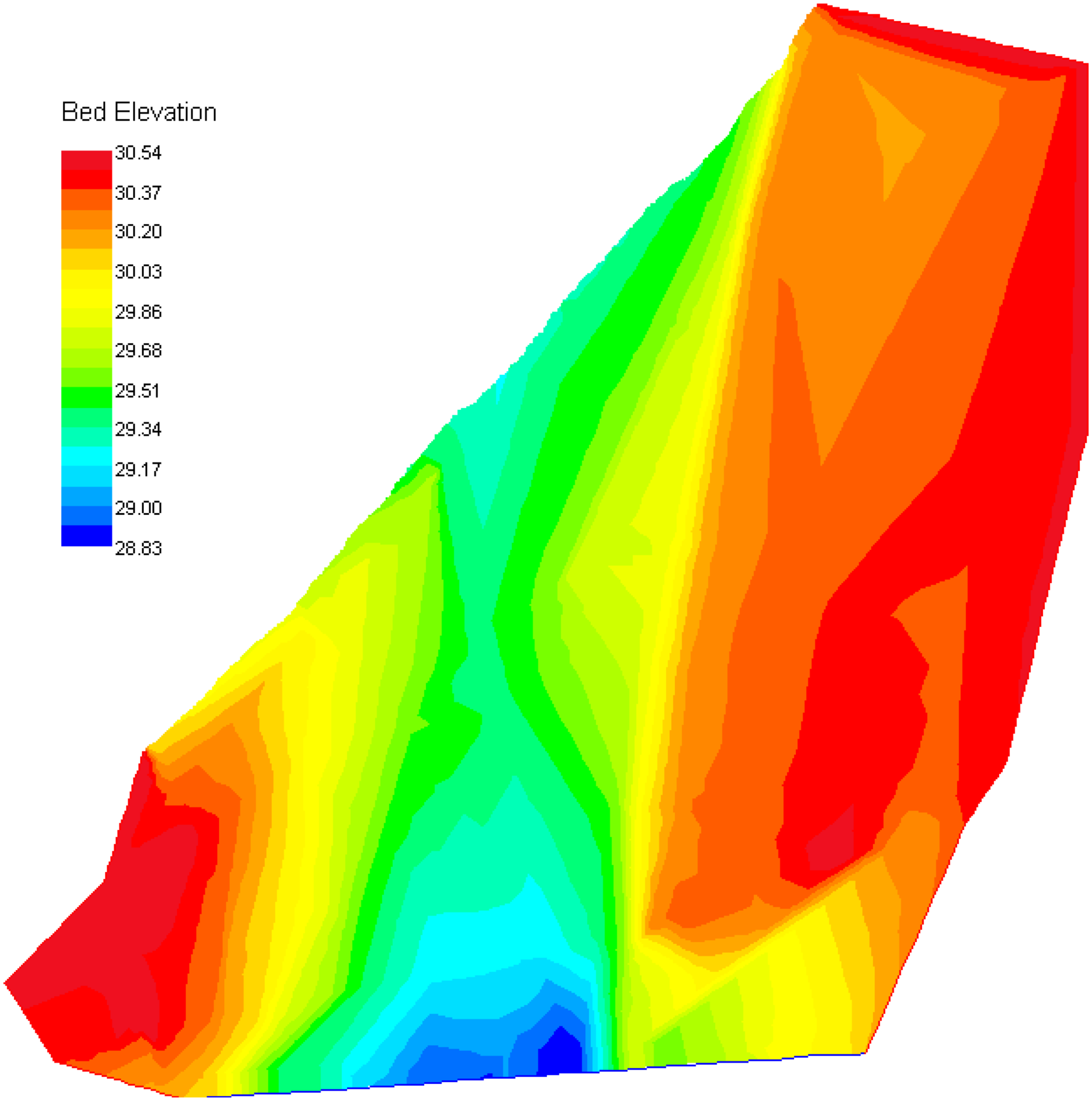
Units of Bed Elevation are meters.

PRE-RESTORATION SITE 2



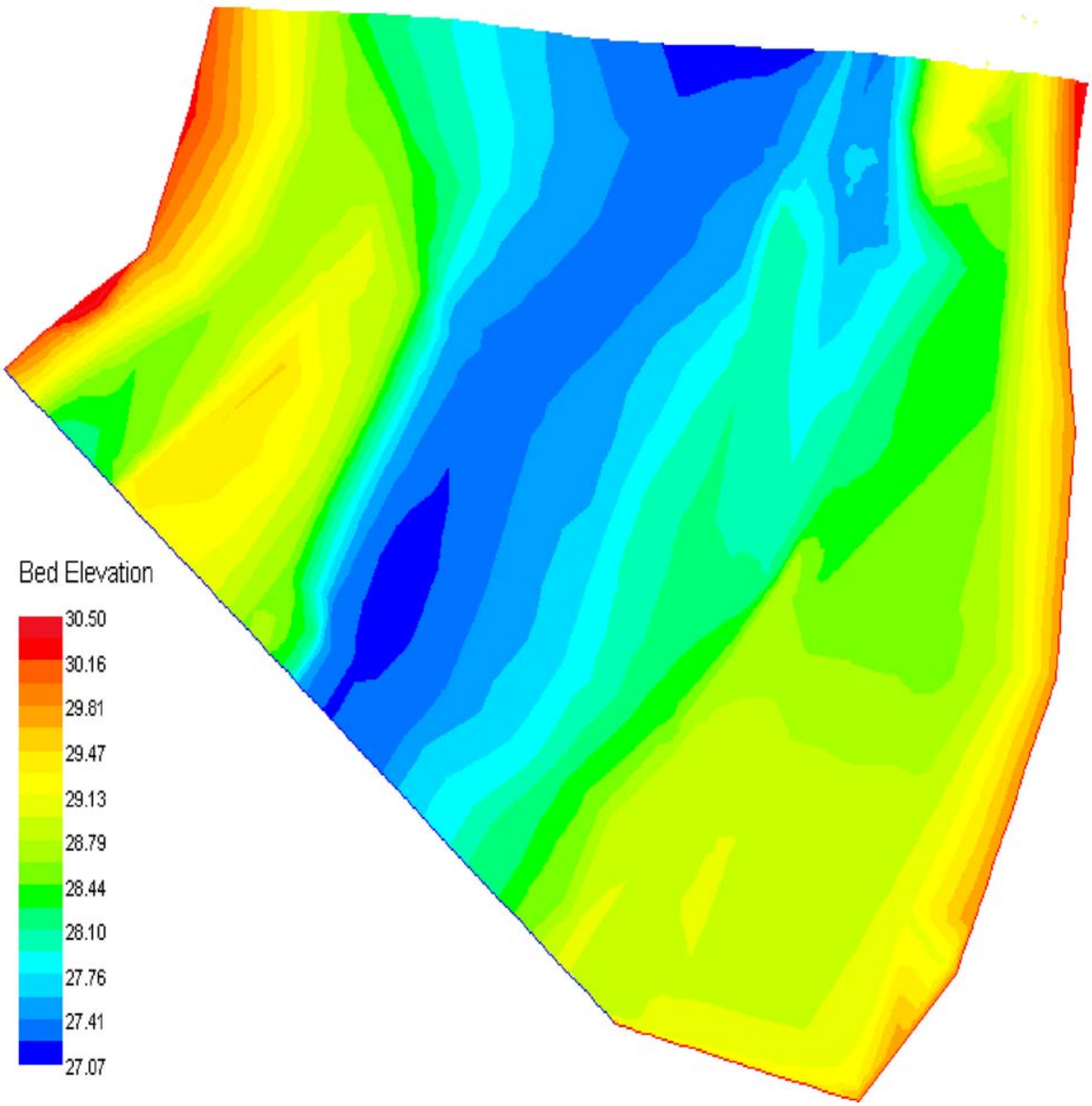
Units of Bed Elevation are in meters.

PRE-RESTORATION SITE 3



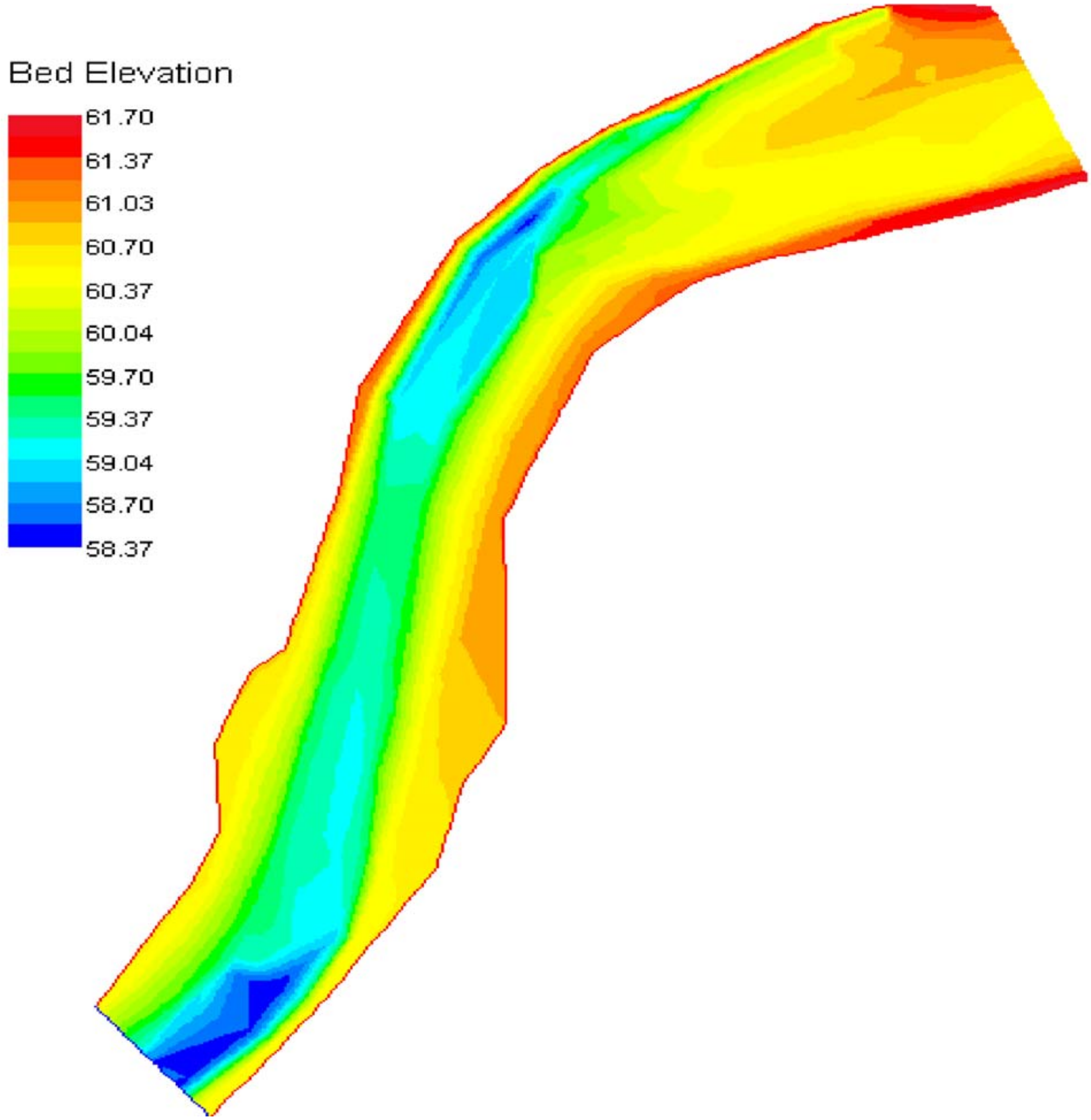
Units of Bed Elevation are in meters.

PRE-RESTORATION SITE 4



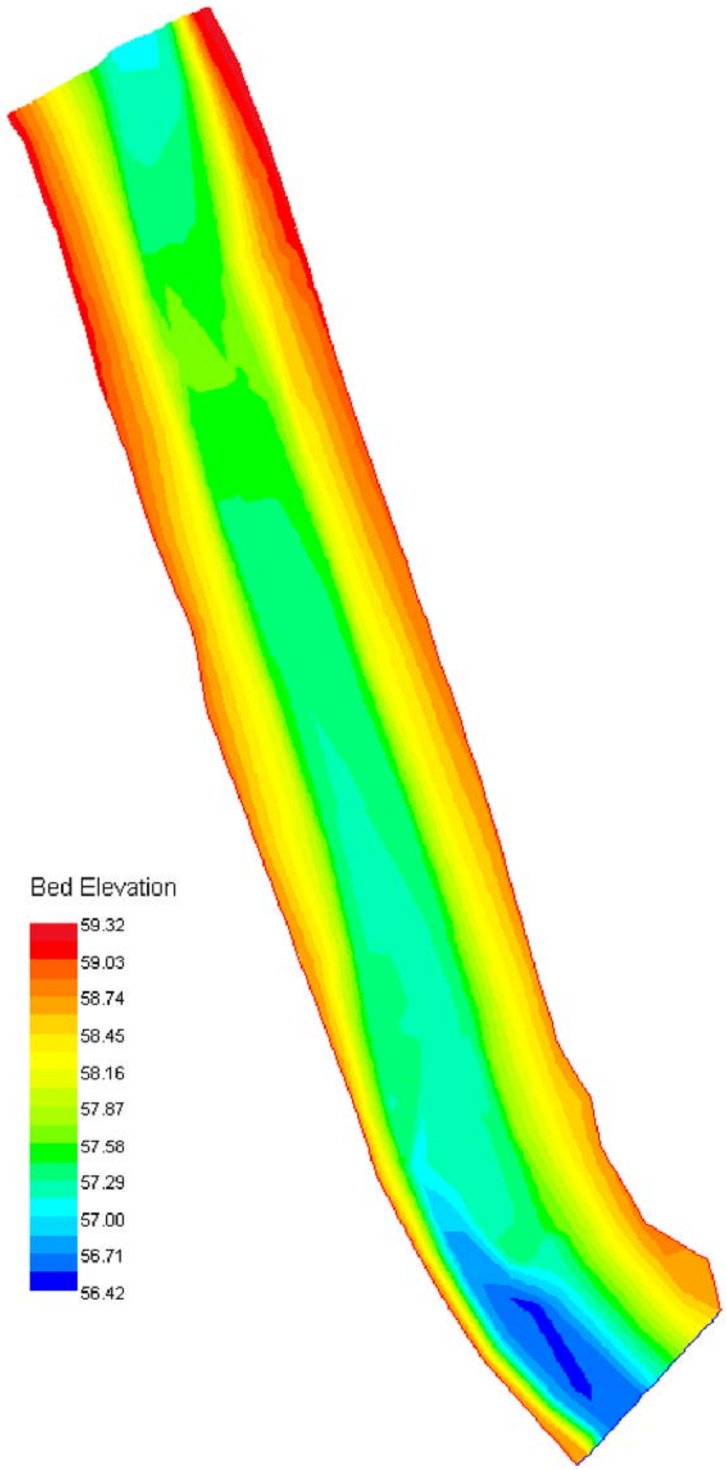
Units of Bed Elevation are in meters.

POST-RESTORATION SITE 1



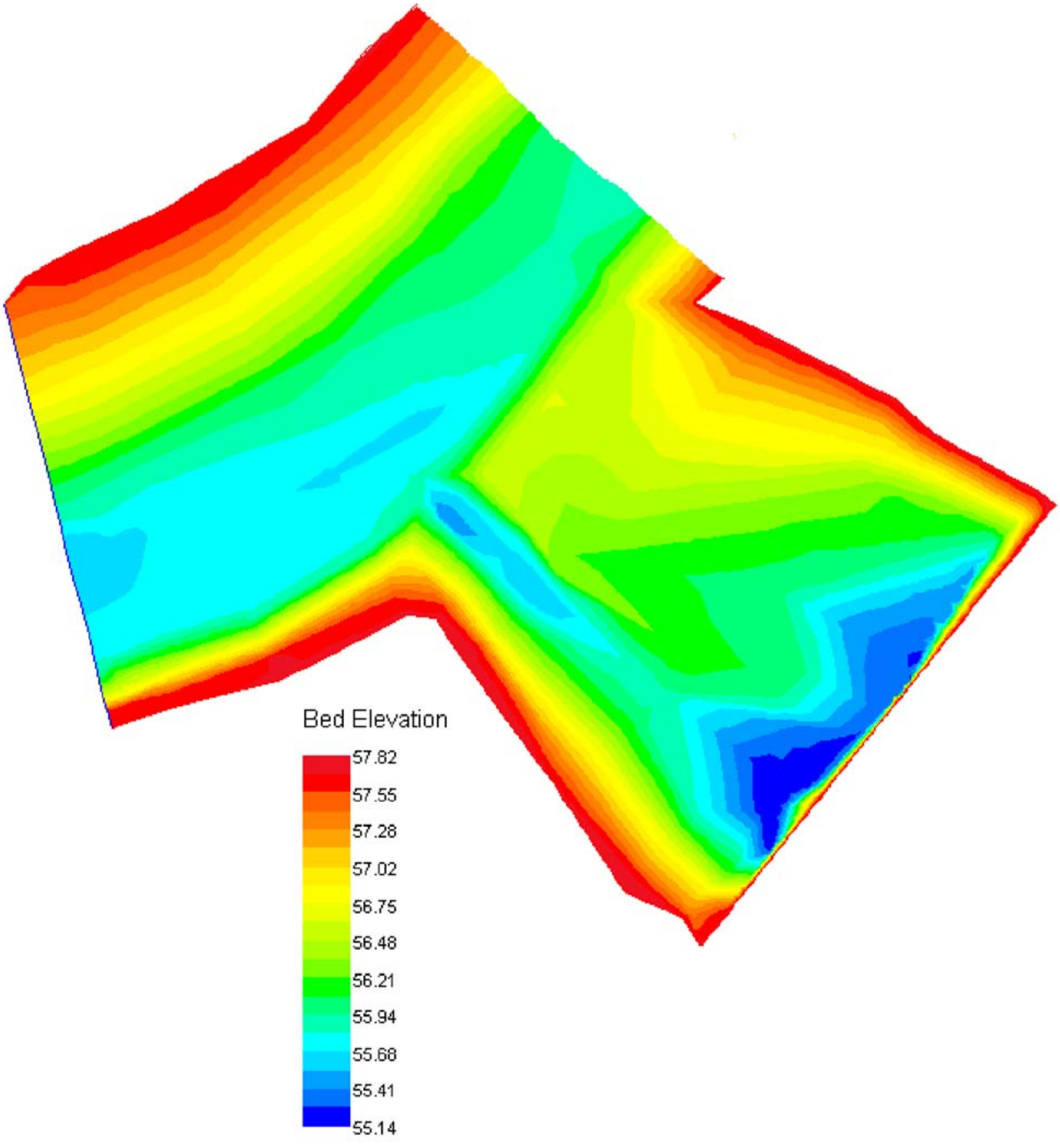
Units of Bed Elevation are in meters.

POST-RESTORATION SITE 2



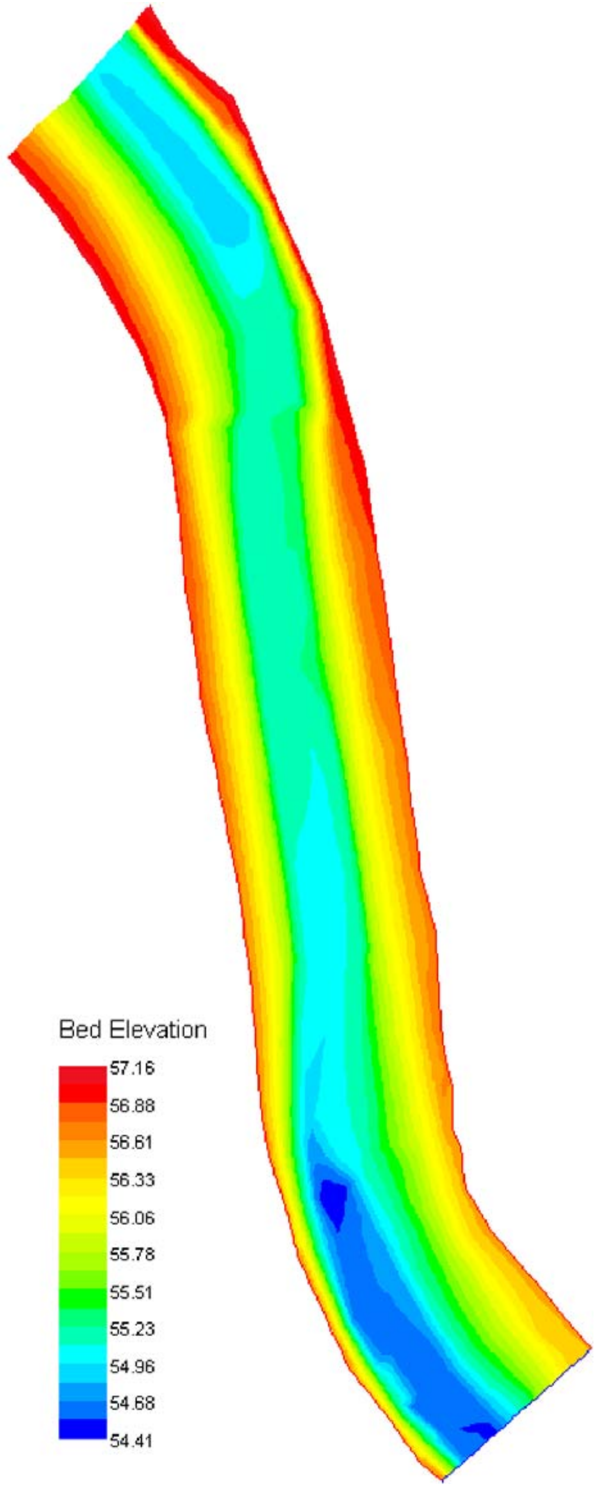
Units of Bed Elevation are in meters.

POST-RESTORATION SITE 3



Units of Bed Elevation are in meters.

POST-RESTORATION SITE 4



Units of Bed Elevation are in meters.

APPENDIX D
2-D WSEL CALIBRATION

Calibration Statistics

Site Name	Flow (cfs)	% Nodes within 0.1'	Nodes	QI	Net Q	Sol Δ	Max F
Pre-restoration							
Site 1	1162	72%	8861	0.30	0.5%	0.000004	6.07
Site 2	2900	79%	3450	0.30	0.01%	< 0.000001	0.79
Site 3	1162	83%	2230	0.31	1.6%	0.000006	5.91
Site 4	2900	85%	2735	0.31	0.004%	< 0.000001	0.36
Post-restoration							
Site 1	1047	92%	5362	0.30	0.003%	< 0.000001	1.44
Site 2	1047	77%	3104	0.30	0.01%	< 0.000001	1.03
Site 3	2600	92%	2666	0.31	1.76%	0.000009	0.55
Site 4	1047	90%	3550	0.31	0.03%	< 0.000001	0.80

Study Sites Transect 2
Difference (measured vs. pred. WSELs)

Site Name	Br Multiplier	Average	Standard Deviation	Maximum
Pre-Restoration				
Site 1	0.3	0.57	0.01	0.58
Site 2	1.2	0.01	0.03	0.10
Site 3	0.3	0.34	0.04	0.40
Site 4	1	0.03	0.01	0.05
Post-restoration				
Site 1	0.3	0.12	0.04	0.18
Site 2	0.3	0.19	0.01	0.22
Site 3	0.3	0.08	0.02	0.11
Site 3 XS 2 LB	0.3	0.08	0.02	0.10
Site 3 XS 2 RB	0.3	0.09	0.004	0.10
Site 4	0.3	0.34	0.03	0.39

APPENDIX E
VELOCITY VALIDATION STATISTICS

Measured Velocities less than 3 ft/s
Difference (measured vs. pred. velocities, ft/s)

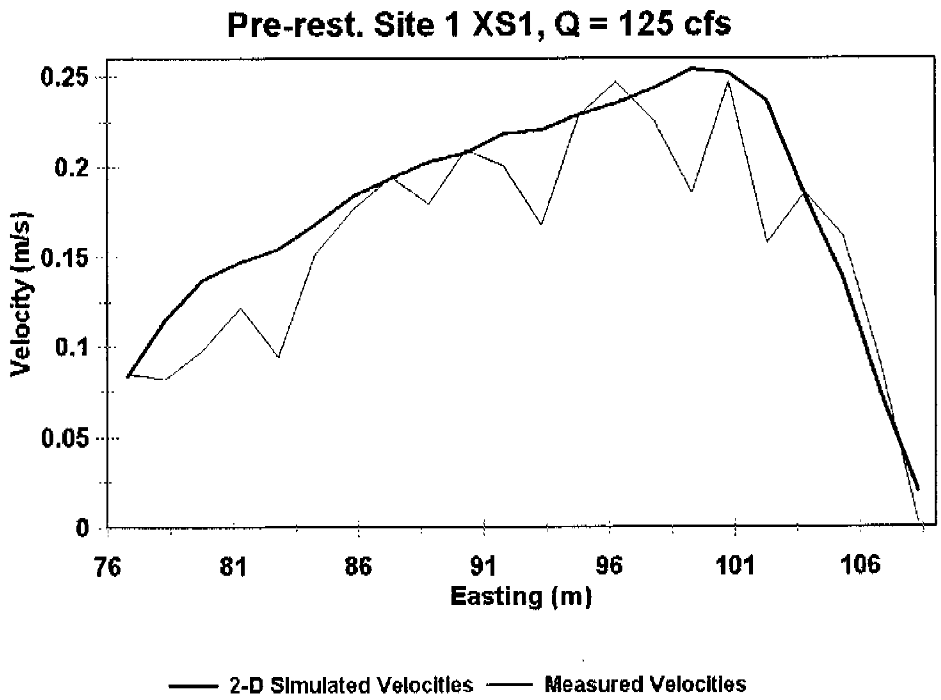
Site Name	Number of Observations	Average	Standard Deviation	Maximum
Pre-restoration				
Site 1	89	0.57	0.77	4.25
Site 2	106	0.42	0.37	1.71
Site 3	87	0.55	0.55	2.43
Site 4	97	0.26	0.25	1.05
Post-restoration				
Site 1	91	0.41	0.43	2.17
Site 2	91	0.50	0.49	2.08
Site 3	78	0.32	0.33	1.57
Site 4	88	0.41	0.43	2.59

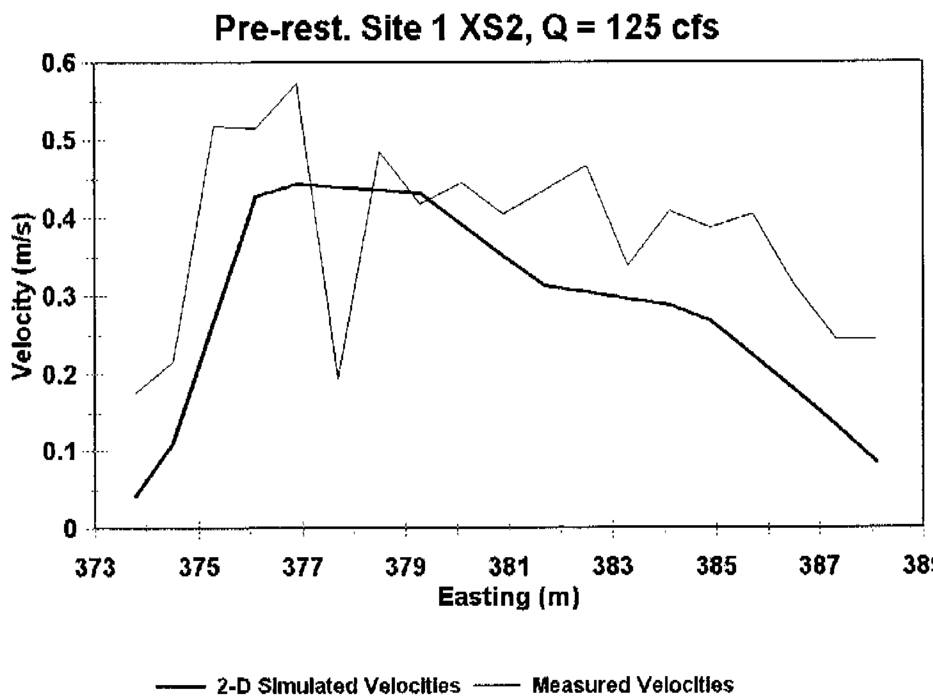
Measured Velocities greater than 3 ft/s
Percent Difference (measured vs. pred. velocities)

Site Name	Number of Observations	Average	Standard Deviation	Maximum
Pre-restoration				
Site 1	3	71%	27%	100%
Site 2	0	---	---	---
Site 3	6	24%	22%	74%
Site 4	0	---	---	---
Post-restoration				
Site 1	6	22%	30%	87%
Site 2	5	29%	12%	52%
Site 3	12	12%	9%	26%
Site 4	2	4%	4%	8%

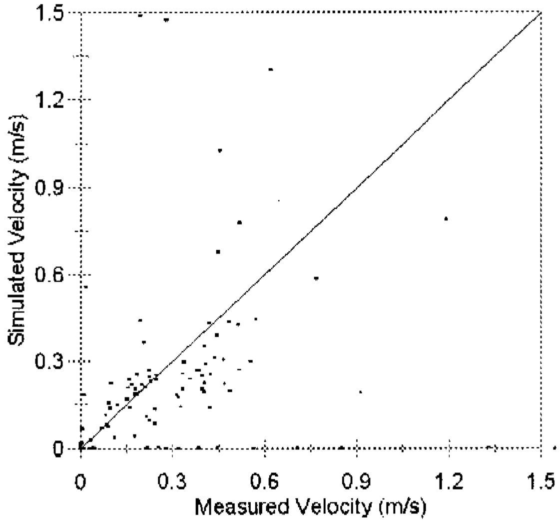
All differences were calculated as the absolute value of the difference between the measured and simulated velocity.

Pre-restoration Site 1

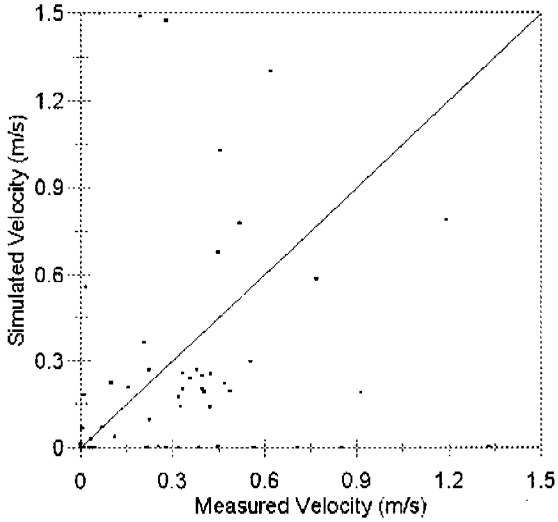




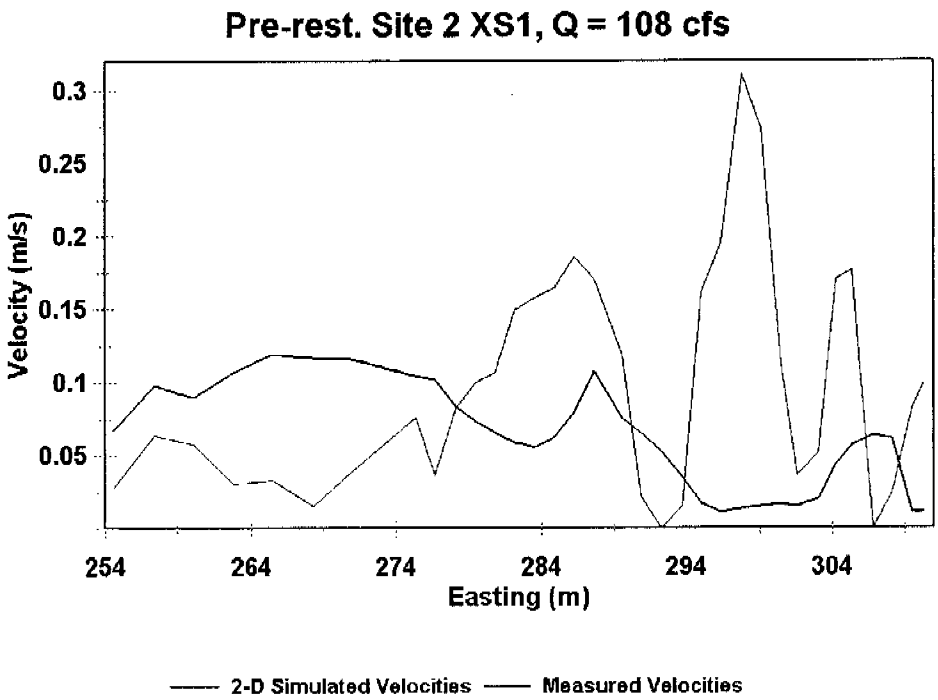
Pre-restoration Site 1
All Validation Velocities

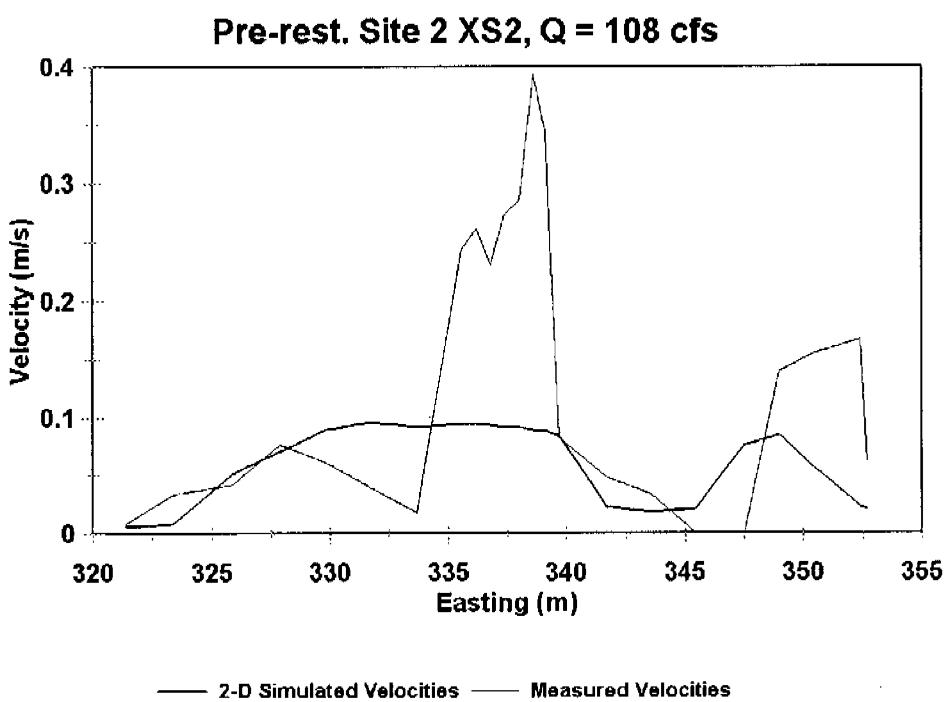


Pre-restoration Site 1
Between Transect Validation Velocities

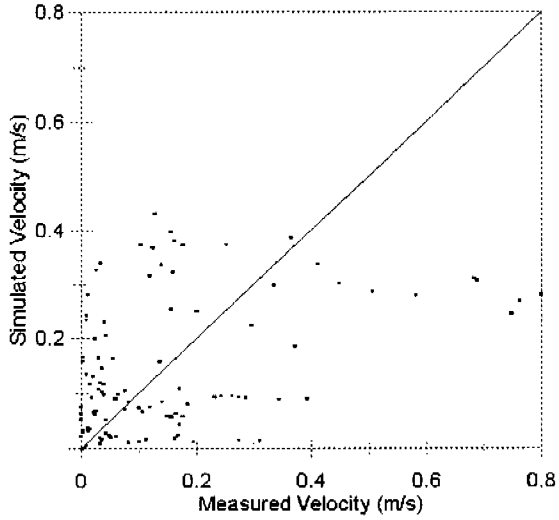


Pre-restoration Site 2





Pre-restoration Site 2
All Validation Velocities



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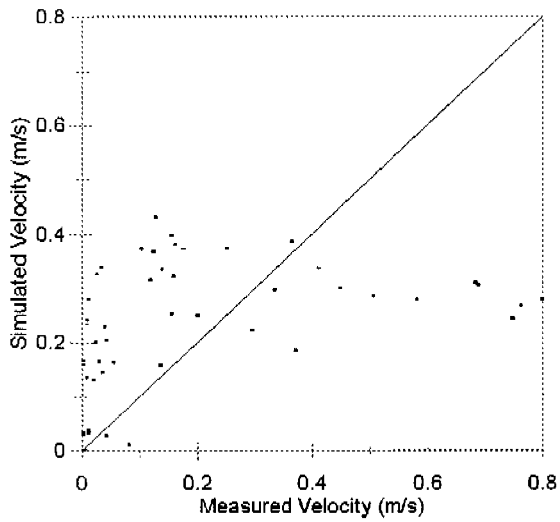
Between Transect Validation Velocities



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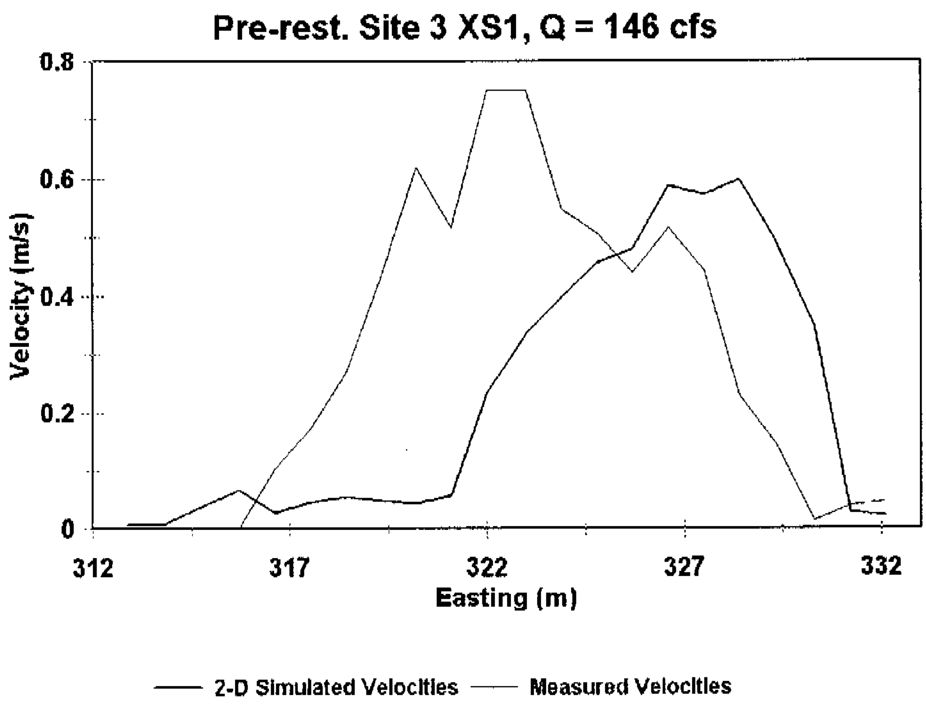
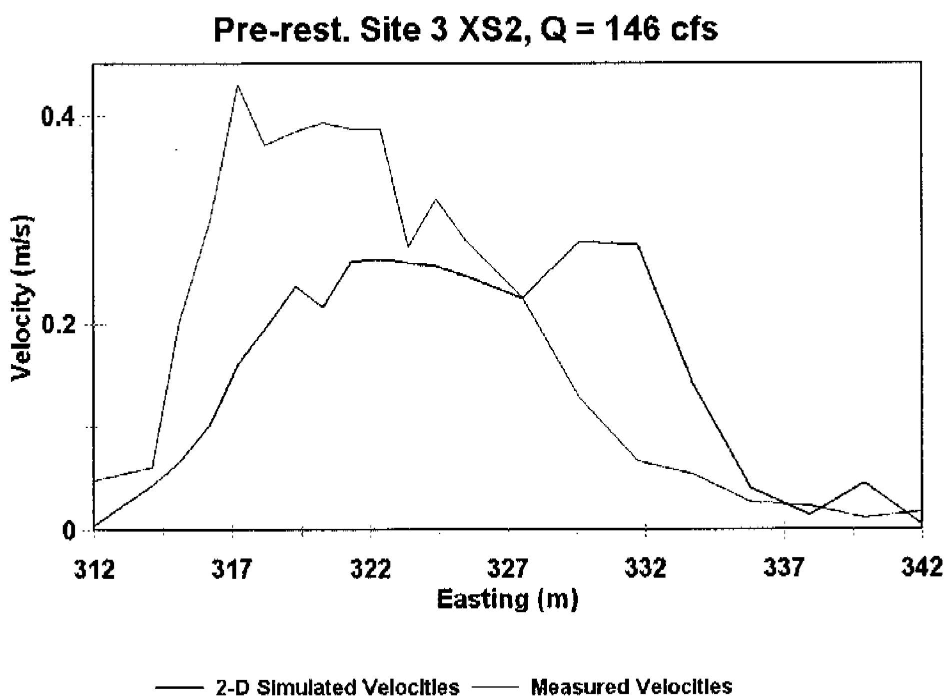
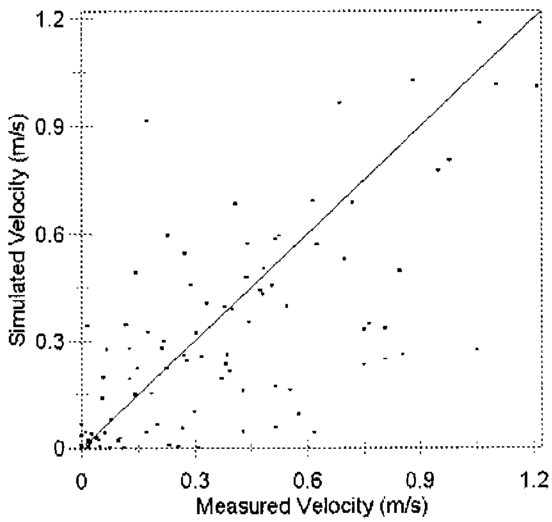
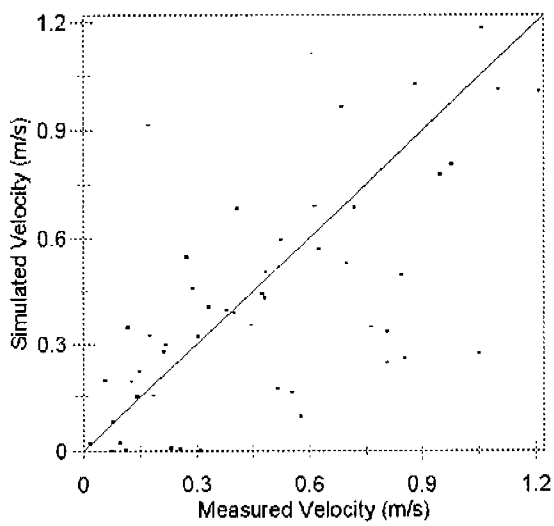




Pre-restoration Site 3
All Validation Velocities



Pre-restoration Site 3
Between Transect Validation Velocities



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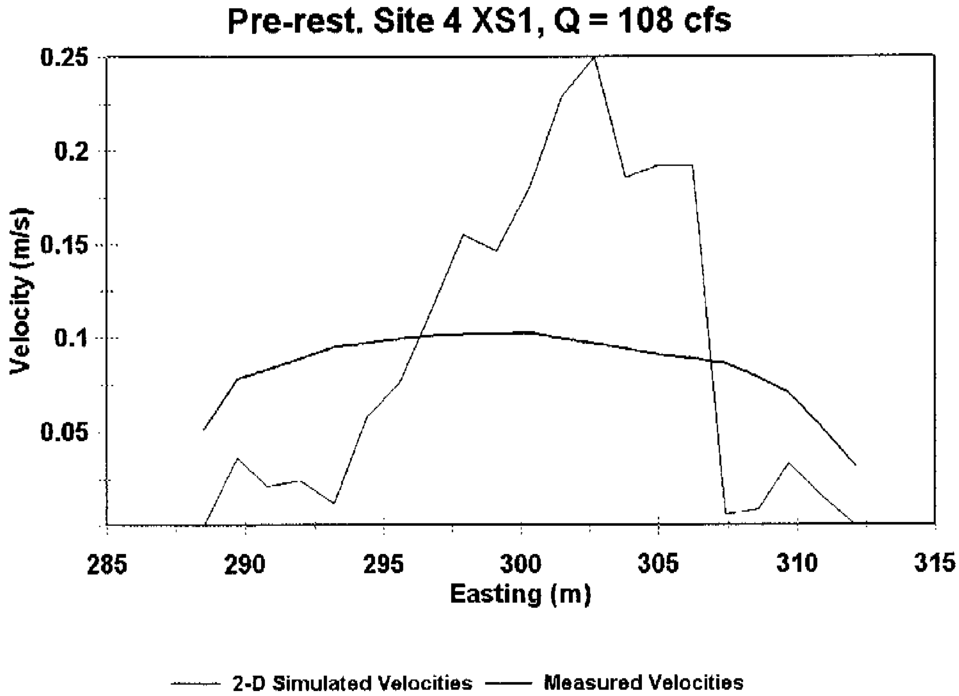
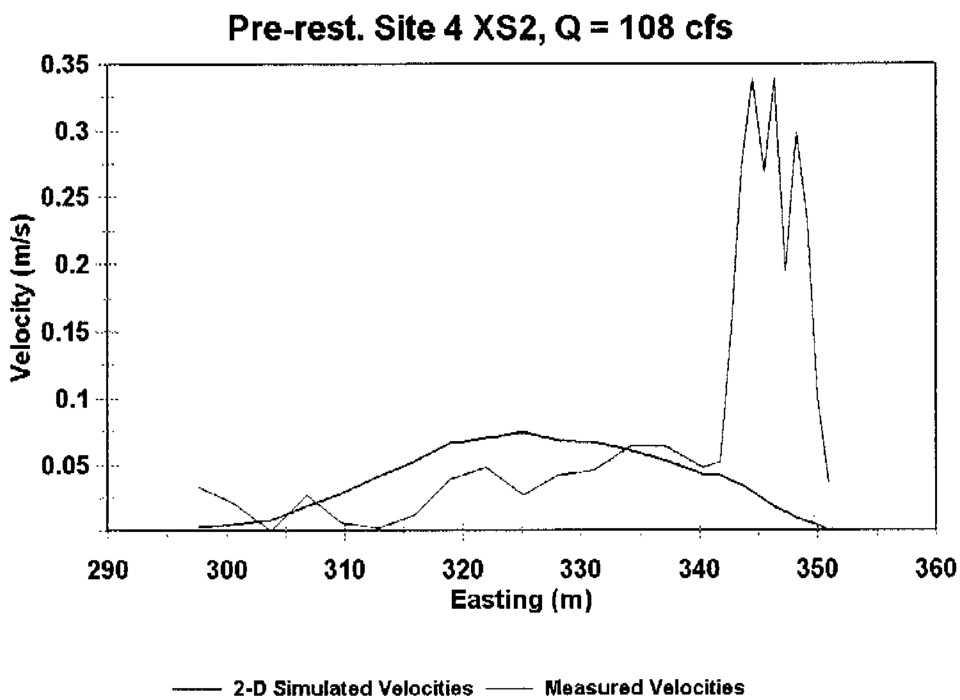
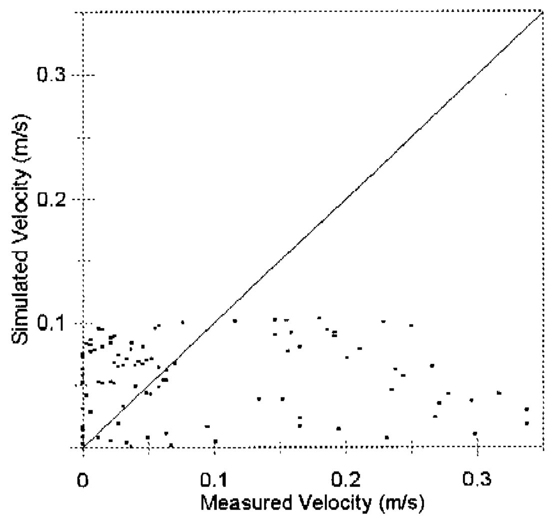
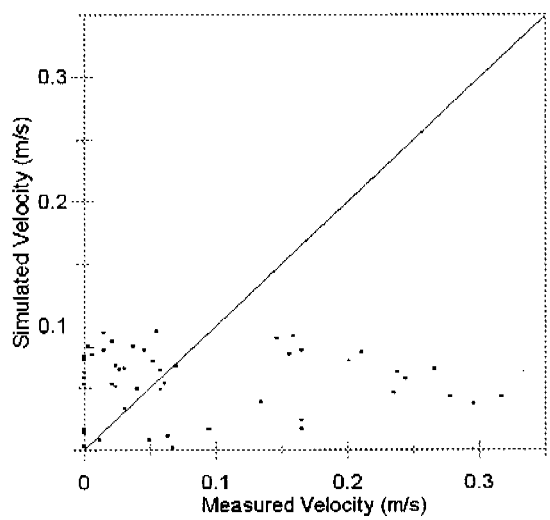




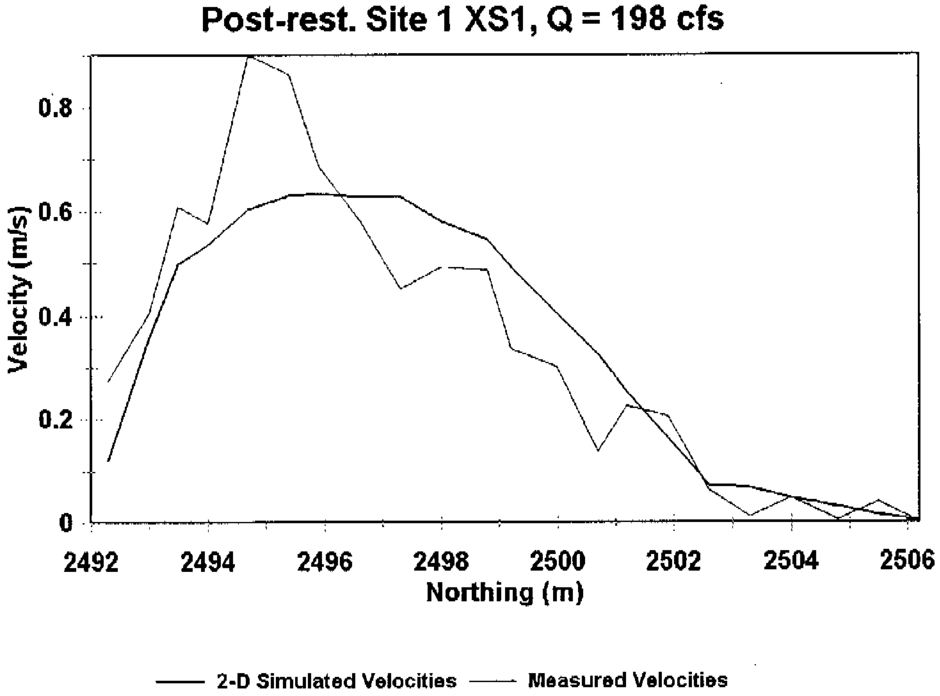
Pre-restoration Site 4
All Validation Velocities

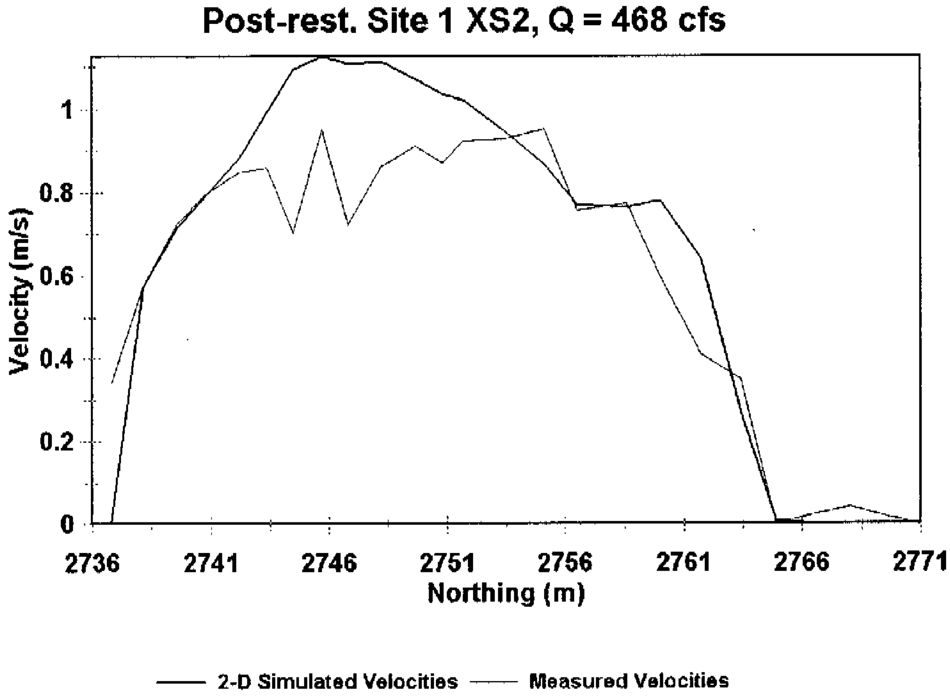


Pre-restoration Site 4
Between Transect Validation Velocities

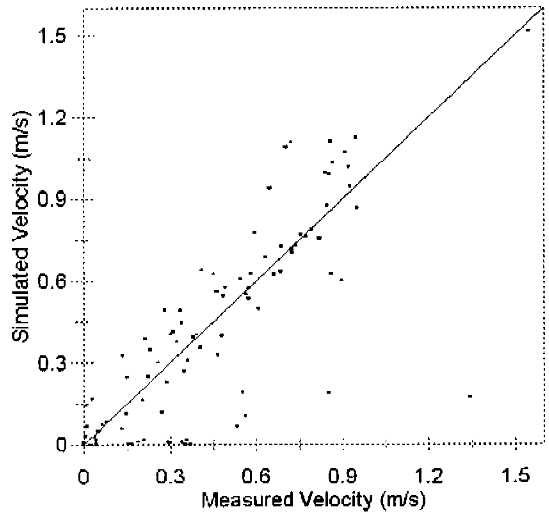


Post-restoration Site 1

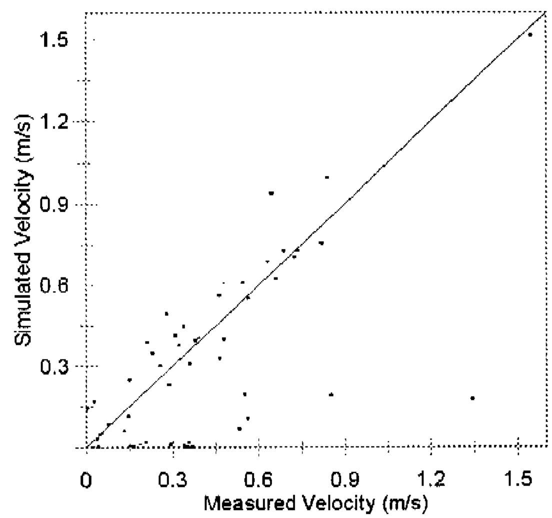




Post-restoration Site 1
All Validation Velocities



Post-restoration Site 1
Between Transect Validation Velocities



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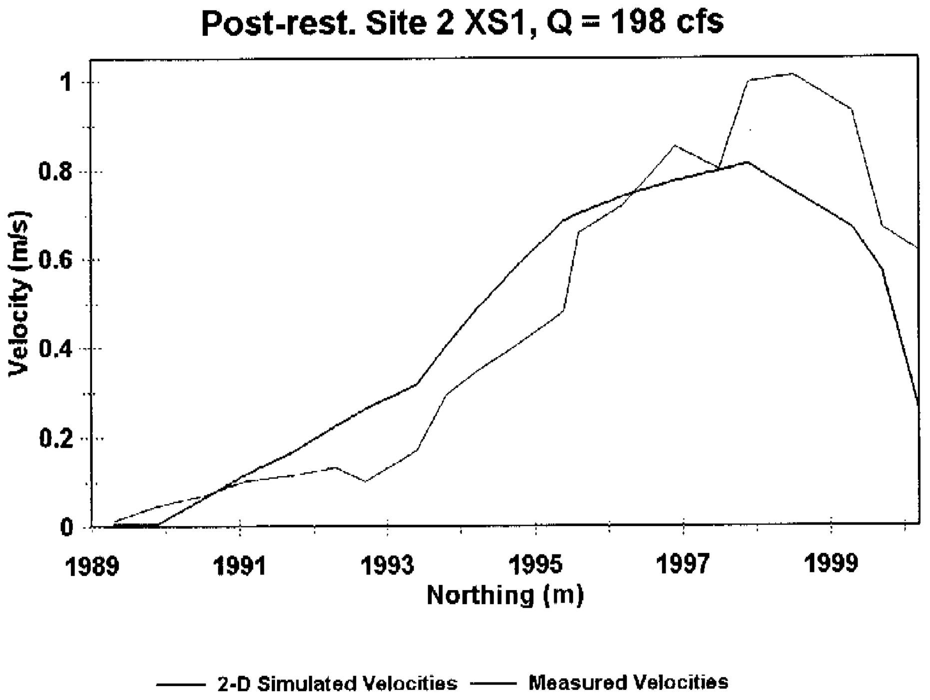

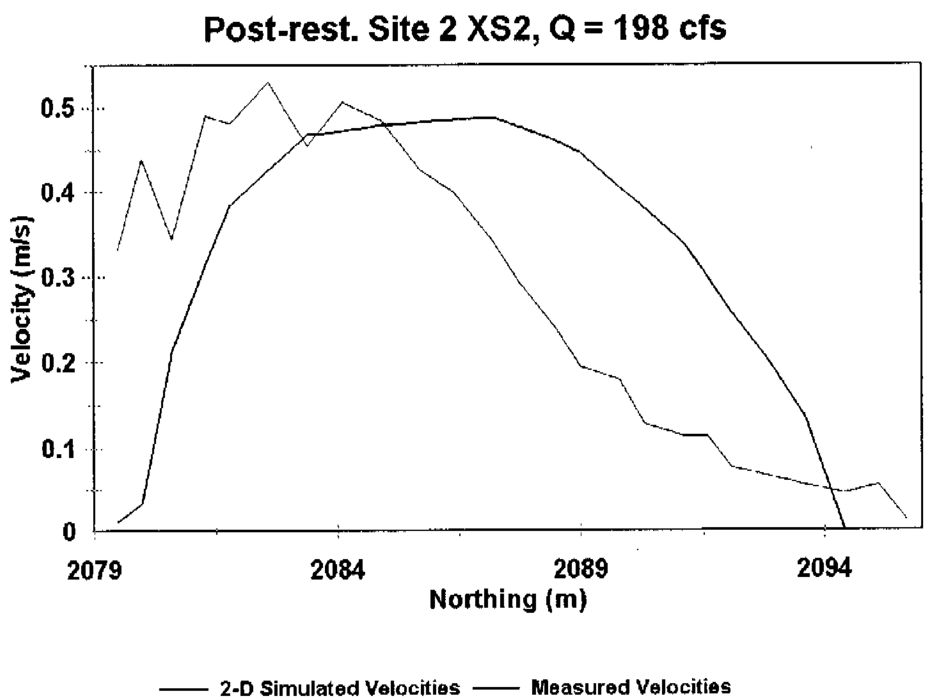

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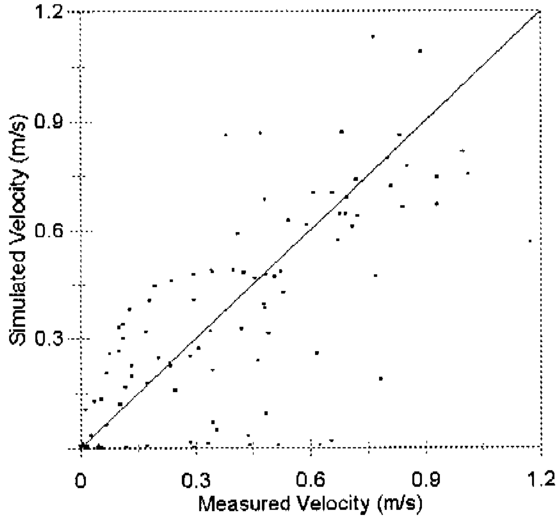
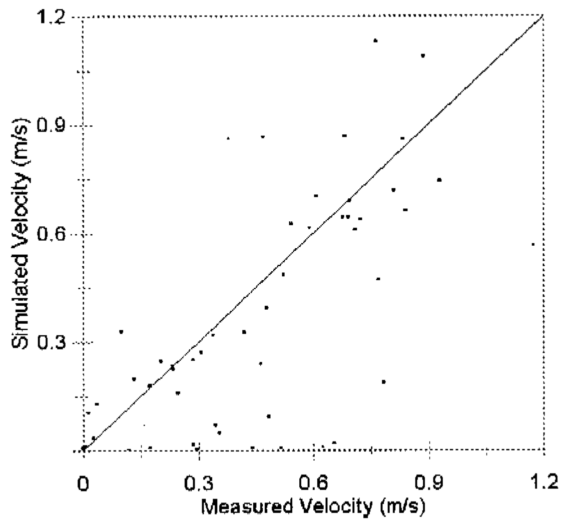
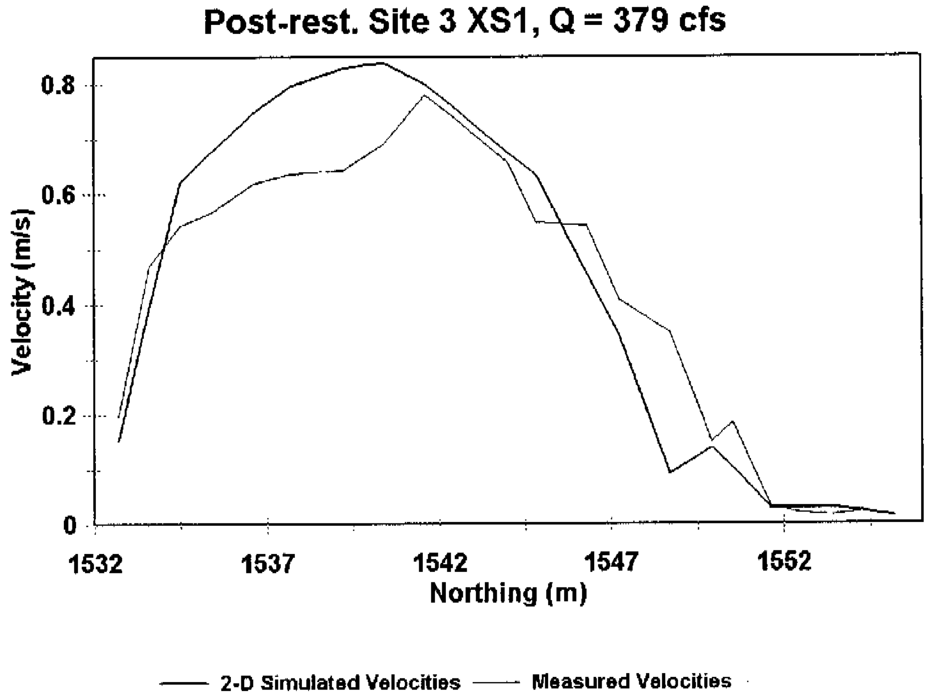
All Validation Velocities

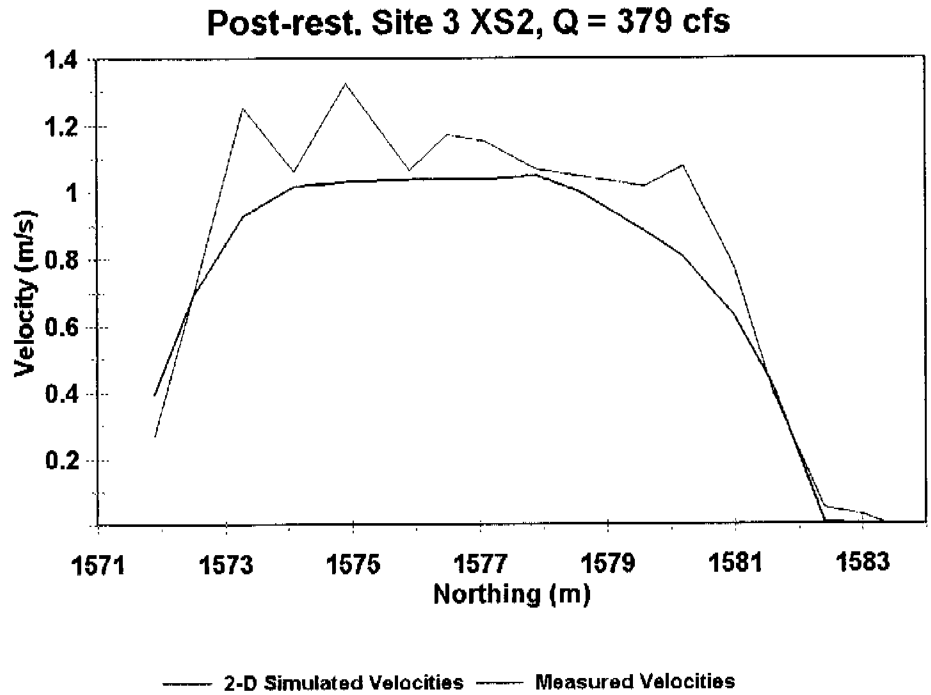


Post-restoration Site 2
Between Transect Validation Velocities

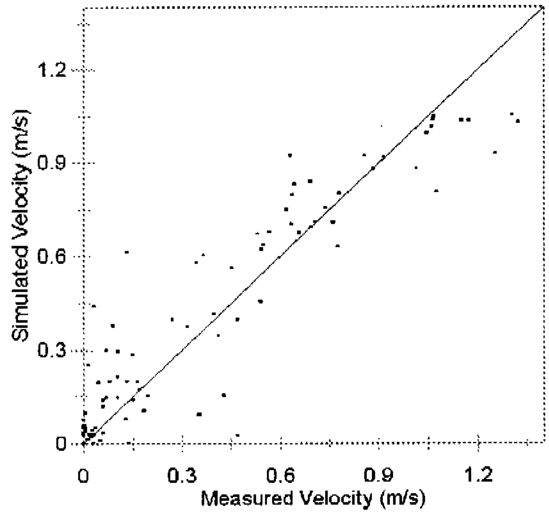


Post-restoration Site 3

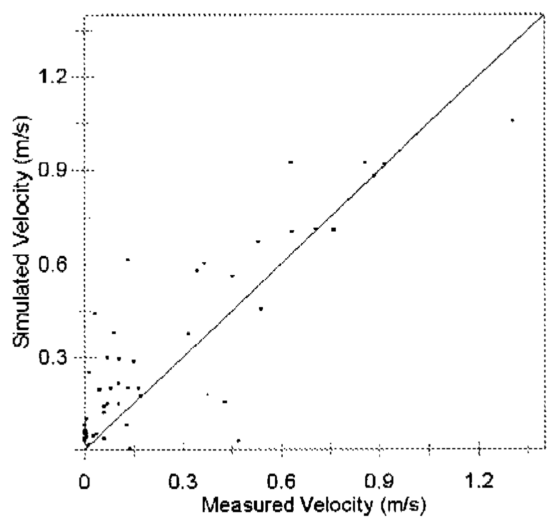




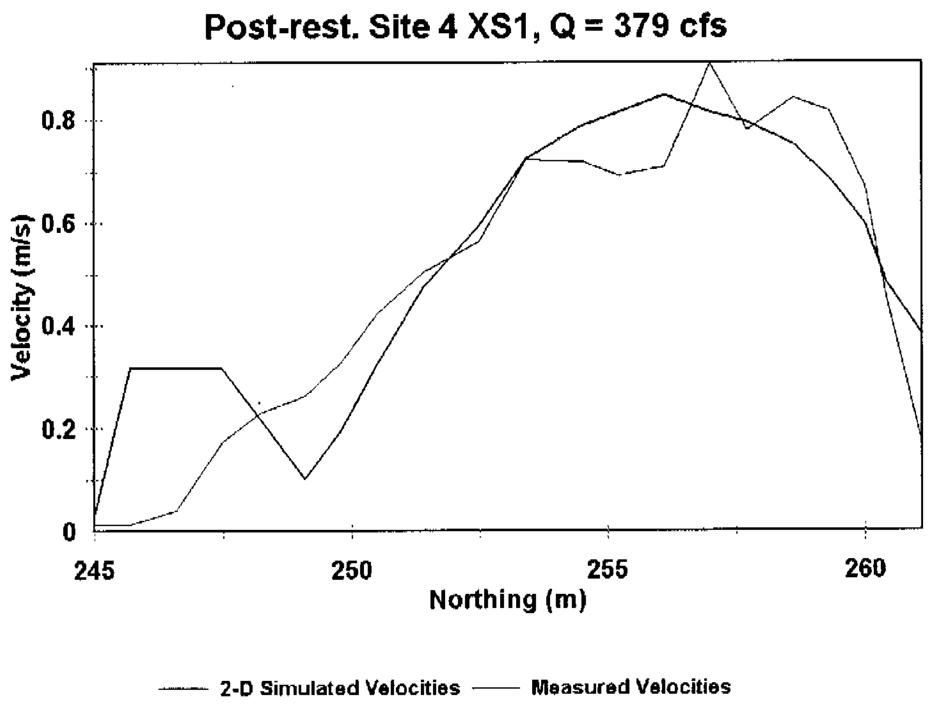
Post-restoration Site 3
All Validation Velocities

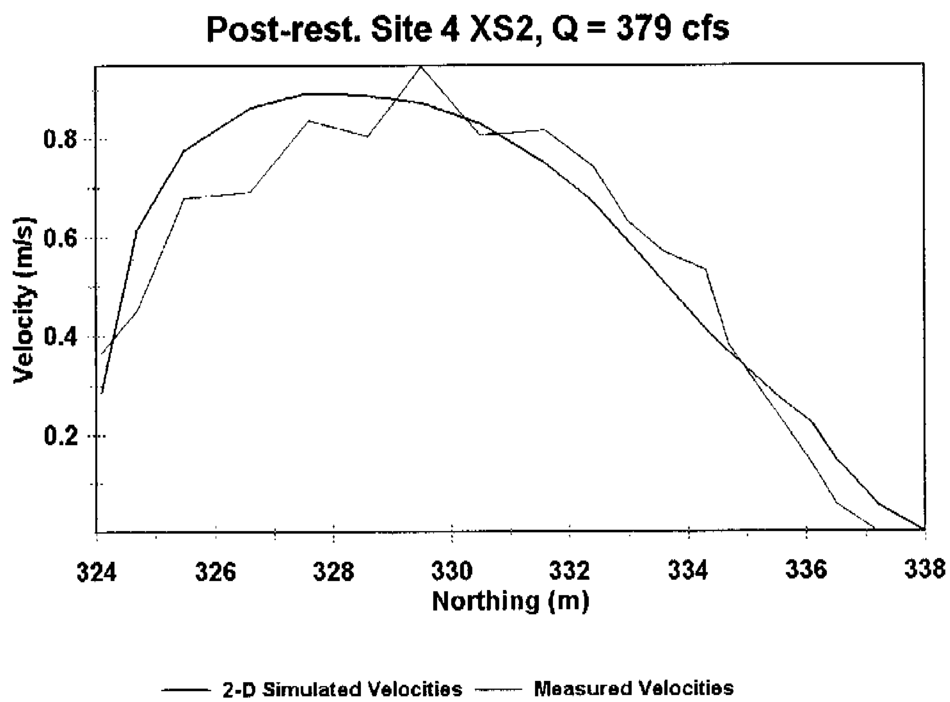


Post-restoration Site 3
Between Transect Validation Velocities

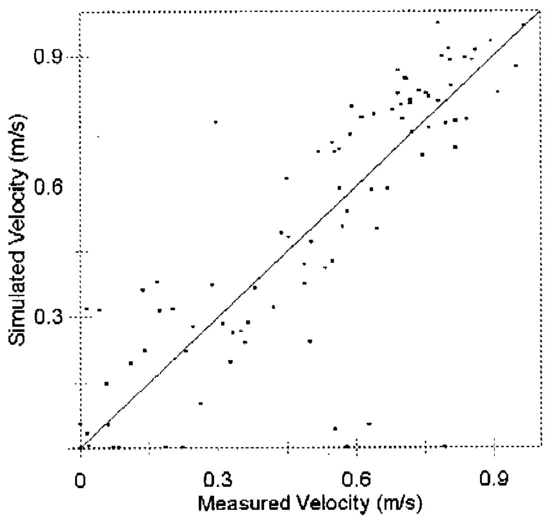


Post-restoration Site 4

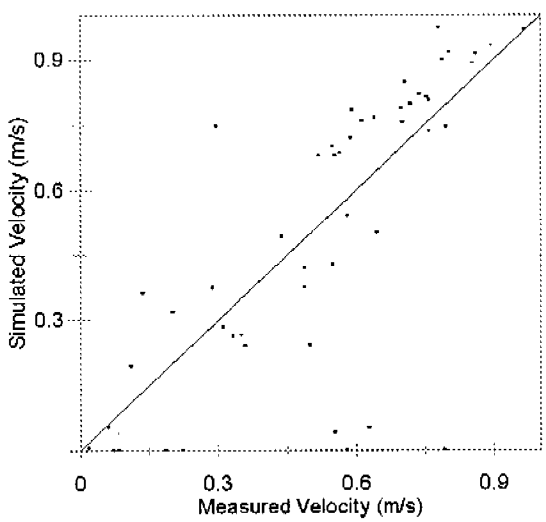




Post-restoration Site 4
All Validation Velocities



Post-restoration Site 4
Between Transect Validation Velocities



APPENDIX F
SIMULATION STATISTICS

Pre-Restoration Site 1

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.6%	0.000001	1.52
200	0.1%	0.000008	2.71
300	0.1%	0.000005	2.48
400	0.8%	0.000002	3.71
500	0.1%	0.000008	3.53
600	0.1%	0.000008	3.89
700	0.002%	0.000003	3.43
800	0.6%	0.000002	3.73
900	0.05%	0.000008	4.56
1000	0.1%	0.000003	4.89
1100	0.02%	0.000001	10.79
1200	0.2%	0.000005	5.55
1300	0.01%	0.000002	8.80
1400	0.01%	< 0.000001	9.83
1500	0.005%	< 0.000001	12.73
1600	0.004%	0.000002	6.11
1700	0.004%	< 0.000001	8.12
1800	0.002%	< 0.000001	5.98
1900	0.002%	< 0.000001	4.55
2000	0.002%	< 0.000001	8.62
2100	0.002%	< 0.000001	6.76
2200	0.01%	0.000001	5.52
2300	0.002%	< 0.000001	4.45
2400	0.001%	< 0.000001	3.99
2500	0.003%	< 0.000001	3.69
2600	0.003%	0.000007	3.45
2700	0.004%	< 0.000001	3.26
2800	0.01%	< 0.000001	3.12
2900	0.01%	< 0.000001	3.43

Pre-Restoration Site 2

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.4%	0.000006	0.26
200	0.2%	< 0.000001	0.24
300	0.3%	< 0.000001	0.25
400	0.1%	< 0.000001	0.26
500	0.01%	< 0.000001	0.31
600	0.01%	< 0.000001	0.52
700	0.02%	< 0.000001	0.49
800	0.005%	< 0.000001	0.45
900	0.03%	< 0.000001	0.47
1000	0.04%	< 0.000001	0.57
1100	0.1%	< 0.000001	0.56
1200	0.2%	< 0.000001	1.00
1300	0.8%	0.000001	1.84
1400	0.8%	0.000002	2.38
1500	0.1%	< 0.000001	1.56
1600	0.1%	< 0.000001	1.26
1700	0.04%	< 0.000001	4.13
1800	0.1%	< 0.000001	1.82
1900	0.2%	< 0.000001	1.22
2000	0.2%	< 0.000001	2.76
2100	0.2%	0.000009	1.65
2200	0.3%	0.000005	1.21
2300	0.3%	< 0.000001	1.00
2400	0.005%	< 0.000001	1.20
2500	0.02%	< 0.000001	1.06
2600	0.03%	< 0.000001	0.97
2700	0.03%	< 0.000001	0.88
2800	0.01%	< 0.000001	0.82
2900	0.01%	< 0.000001	0.79

Pre-Restoration Site 3

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.6%	0.000007	0.90
200	0.9%	0.000002	1.00
300	3.3%	0.000005	1.01
400	5.6%	< 0.000001	1.02
500	3.1%	< 0.000001	2.41
600	2.1%	< 0.000001	5.70
700	1.6%	< 0.000001	3.27
800	1.4%	0.000002	2.81
900	1.4%	0.000004	3.61
1000	1.5%	0.000006	4.39
1100	1.9%	0.000008	4.66
1200	1.5%	0.000005	4.36
1300	1.8%	0.000002	4.16
1400	2.1%	0.000004	3.70
1500	2.3%	< 0.000001	3.37
1600	2.7%	0.000003	3.23
1700	2.4%	0.000009	3.24
1800	2.1%	< 0.000001	5.95
1900	2.0%	0.000005	3.61
2000	2.0%	0.000006	5.24
2100	3.5%	0.000008	2.41
2200	3.3%	0.000003	2.40
2300	4.5%	0.000004	2.15
2400	5.0%	0.000005	2.02
2500	4.3%	0.000003	10.65
2600	5.7%	0.000004	10.16
2700	5.8%	0.000003	2.71
2800	6.1%	< 0.000001	2.61
2900	6.2%	< 0.000001	2.52

Pre-Restoration Site 4

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.6%	< 0.000001	0.05
200	0.5%	< 0.000001	0.07
300	0.5%	< 0.000001	0.08
400	0.5%	< 0.000001	0.15
500	0.3%	< 0.000001	0.12
600	0.2%	< 0.000001	0.11
700	0.1%	< 0.000001	0.23
800	0.01%	< 0.000001	3.88
900	0.1%	< 0.000001	1.36
1000	0.3%	< 0.000001	1.00
1100	0.005%	< 0.000001	1.00
1200	0.001%	< 0.000001	0.56
1300	0.0004%	< 0.000001	0.50
1400	0.004%	< 0.000001	0.47
1500	0.01%	< 0.000001	0.44
1600	0.01%	< 0.000001	0.42
1700	0.01%	< 0.000001	0.40
1800	0.01%	< 0.000001	0.39
1900	0.002%	< 0.000001	0.38
2000	0.001%	< 0.000001	0.37
2100	0.003%	< 0.000001	0.37
2200	0.005%	< 0.000001	0.37
2300	0.01%	< 0.000001	0.37
2400	0.01%	< 0.000001	0.36
2500	0.01%	< 0.000001	0.36
2600	0.01%	< 0.000001	0.36
2700	0.01%	< 0.000001	0.36
2800	0.002%	< 0.000001	0.36
2900	0.004%	< 0.000001	0.36

Post-restoration Site 1

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.2%	0.000006	2.18
200	0.04%	0.000003	2.66
300	1.6%	0.000002	1.63
400	1.0%	0.000006	1.57
500	0.04%	0.000004	1.66
600	0.001%	0.000004	2.47
700	0.02%	0.000003	2.58
800	0.01%	0.000007	2.21
900	0.02%	0.000005	1.71
1000	0.002%	< 0.000001	1.46
1100	0.01%	< 0.000001	1.35
1200	0.01%	< 0.000001	1.26
1300	0.01%	< 0.000001	1.22
1400	0.01%	< 0.000001	1.16
1500	0.0002%	0.000001	1.20
1600	0.004%	0.000003	1.25
1700	0.01%	0.000006	1.27
1800	0.02%	0.000005	1.27
1900	0.002%	0.000006	1.26
2000	0.02%	< 0.000001	1.27
2100	0.03%	< 0.000001	1.31
2200	0.03%	< 0.000001	1.35
2300	0.03%	< 0.000001	1.39
2400	0.04%	< 0.000001	1.44
2500	0.03%	0.000006	1.48
2600	0.08%	0.000004	1.54

Post-restoration Site 2

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.1%	< 0.000001	1.46
200	0.04%	< 0.000001	1.14
300	0.06%	< 0.000001	1.05
400	0.07%	0.000008	0.87
500	0.04%	< 0.000001	1.08
600	0.01%	0.000009	1.24
700	0.03%	< 0.000001	1.11
800	0.04%	< 0.000001	1.00
900	0.01%	< 0.000001	0.98
1000	0.01%	< 0.000001	1.01
1100	0.01%	< 0.000001	1.11
1200	0.01%	< 0.000001	1.00
1300	0.003%	0.000009	0.96
1400	0.08%	0.000009	1.01
1500	0.01%	< 0.000001	1.02
1600	0.01%	< 0.000001	1.05
1700	0.01%	< 0.000001	0.94
1800	0.01%	< 0.000001	0.97
1900	0.01%	< 0.000001	1.01
2000	0.01%	< 0.000001	1.00
2100	0.05%	0.000006	0.99
2200	0.00008%	0.000005	1.07
2300	0.01%	0.000004	1.04
2400	0.02%	0.000007	1.08
2500	0.06%	0.000007	1.10
2600	0.01%	0.000002	1.12

Post-restoration Site 3

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.04%	0.000006	0.49
200	0.02%	0.000001	0.49
300	0.02%	0.000008	1.29
400	0.6%	0.000002	0.37
500	0.07%	0.000003	0.47
600	0.98%	0.000009	0.59
700	0.3%	0.000004	0.47
800	0.003%	0.000005	0.53
900	0.03%	0.000008	0.56
1000	0.2%	0.000005	0.54
1100	0.8%	0.000002	0.81
1200	0.1%	< 0.000001	0.58
1300	0.1%	< 0.000001	0.59
1400	0.2%	0.000009	0.62
1500	0.2%	0.000001	0.68
1600	0.2%	0.000005	0.75
1700	0.2%	0.000004	0.75
1800	0.2%	< 0.000001	1.00
1900	0.2%	< 0.000001	1.00
2000	0.2%	< 0.000001	1.00
2100	0.2%	< 0.000001	1.00
2200	0.2%	< 0.000001	1.00
2300	0.2%	< 0.000001	1.00
2400	0.2%	< 0.000001	1.00
2500	0.2%	< 0.000001	1.00
2600	0.1%	< 0.000001	1.00

Post-restoration Site 4

Flow (cfs)	Net Q	Sol Δ	Max F
100	0.1%	< 0.000001	0.63
200	0.1%	< 0.000001	0.59
300	0.4%	< 0.000001	0.61
400	0.3%	< 0.000001	0.59
500	0.01%	< 0.000001	0.62
600	0.001%	< 0.000001	0.67
700	0.01%	< 0.000001	0.68
800	0.02%	< 0.000001	0.69
900	0.0004%	< 0.000001	0.78
1000	0.01%	< 0.000001	0.76
1100	0.01%	< 0.000001	0.76
1200	0.01%	< 0.000001	0.83
1300	0.02%	< 0.000001	0.87
1400	0.04%	< 0.000001	0.85
1500	0.03%	< 0.000001	0.82
1600	0.1%	< 0.000001	1.00
1700	0.1%	< 0.000001	1.00
1800	0.1%	< 0.000001	1.08
1900	0.1%	< 0.000001	2.38
2000	0.1%	< 0.000001	1.24
2100	0.05%	< 0.000001	1.23
2200	0.01%	< 0.000001	1.50
2300	0.1%	< 0.000001	1.65
2400	0.1%	< 0.000001	2.19
2500	0.2%	< 0.000001	2.09
2600	0.3%	0.000004	1.50

APPENDIX G
MERCED RIVER FALL-RUN CHINOOK SALMON SPAWNING AND REARING HSC

FALL-RUN CHINOOK SALMON SPAWNING HSC

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Substrate Composition	SI Value
0.00	0.00	0.00	0.00	0.10	0.00
0.40	0.00	0.30	0.00	1.00	0.08
0.42	0.07	0.67	0.39	1.20	0.71
0.51	0.11	0.72	0.49	1.30	1.00
0.60	0.15	0.82	0.70	2.40	1.00
0.69	0.21	0.87	0.79	3.50	0.50
0.83	0.33	0.91	0.88	4.60	0.00
0.92	0.41	1.01	0.98	100.0	0.00
1.01	0.51	1.06	1.00		
1.10	0.61	1.09	1.00		
1.19	0.70	24.00	0.00		
1.29	0.79	100.00	0.00		
1.38	0.87				
1.47	0.93				
1.65	1.00				
1.74	1.00				
1.83	0.98				
1.92	0.95				
2.01	0.90				
2.11	0.84				
2.20	0.77				
2.29	0.70				
2.47	0.55				
2.56	0.48				
2.65	0.41				
2.74	0.35				
2.88	0.27				
2.95	0.21				
3.02	0.20				
3.15	0.15				
3.29	0.11				
3.38	0.08				
3.47	0.07				
3.56	0.05				
3.65	0.04				
3.75	0.03				
3.84	0.02				
3.93	0.02				
4.06	0.01				
100.00	0.00				

FALL-RUN CHINOOK SALMON FRY REARING HSC

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value	Adjacent Velocity (ft/s)	SI Value
0	0.86	0	0.00	0	0.00	0	0.56
0.10	0.96	0.1	0.00	0.1	0.24	1.83	1.00
0.20	1.00	0.2	0.82	1	0.24	100	1.00
0.25	1.00	0.7	0.94	2	0.24		
0.40	0.95	1.3	1.00	3	0.24		
0.60	0.77	1.8	1.00	3.7	1.00		
0.90	0.40	2.5	0.93	4	1.00		
1.10	0.22	3.0	0.85	4.7	1.00		
1.30	0.13	5.0	0.37	5	1.00		
1.60	0.06	6.0	0.19	5.7	1.00		
2.54	0.02	7.0	0.10	7	0.24		
2.55	0.00	8.0	0.05	8	1.00		
100	0.00	10.0	0.02	9	0.24		
		13.0	0.02	9.7	0.24		
		15.0	0.04	10	0.24		
		16.5	0.04	100	0.00		
		18.6	0.01				
		18.7	0.00				
		100	0.00				

FALL-RUN CHINOOK SALMON JUVENILE REARING HSC

Water Velocity (ft/s)	SI Value	Water Depth (ft)	SI Value	Cover	SI Value	Adjacent Velocity (ft/s)	SI Value
0	0.47	0	0.00	0	0.00	0	0.09
0.20	0.85	0.3	0.00	0.1	0.24	4.14	1.00
0.30	0.96	0.4	0.41	1	0.24	100	1.00
0.40	1.00	1.6	0.90	2	0.24		
0.50	0.98	2.0	0.98	3	0.24		
0.60	0.91	2.2	1.00	3.7	1.00		
1.10	0.35	2.5	1.00	4	1.00		
1.30	0.21	3.0	0.94	4.7	1.00		
1.50	0.13	3.5	0.84	5	1.00		
1.70	0.09	5.5	0.32	5.7	1.00		
2.10	0.06	6.5	0.17	7	0.24		
2.60	0.08	8.0	0.07	8	1.00		
2.75	0.10	9.5	0.04	9	0.24		
3.93	0.00	10.5	0.03	9.7	0.24		
100	0.00	13.5	0.03	10	0.24		
		17.5	0.07	100	0.00		
		19.0	0.07				
		20.0	0.06				
		22.0	0.02				
		23.7	0.01				
		23.8	0.00				
		100	0.00				

APPENDIX H
HABITAT MODELING RESULTS

Pre-restoration fall-run Chinook salmon spawning WUA (ft^2)[21]

Flow (cfs)	Site 1	Site 2	Site 3	Site 4	Total
100	554.7	0	4.4	0	21,305
200	781.9	1.2	13.5	0	39,538
300	1052	3.3	21.9	0	57,947
400	1229.9	7.4	27.7	0	63,063
500	1335.7	13	31.2	0	67,338
600	1388.7	20	30.7	0	70,036
700	1416.6	26	27.8	0	70,641
800	1564.2	32	26.1	0	75,465
900	1610.6	38	24.9	0	77,050
1000	1664	45	25.1	0	78,205
1100	1714.6	50	24.9	0	79,188
1200	1703.2	55	24.9	0	77,467
1300	1678.3	58	25.7	0	74,934
1400	1625.8	61	26.3	0	72,006
1500	1608.8	64	27	0	70,234
1600	1615	66	29.7	0	69,073
1700	1634.2	68	30.4	0	69,094
1800	1593.1	69	33	0	66,940
1900	1540	69	37.8	0	64,166
2000	1500.2	69	44.3	0	62,076
2100	1445.5	68	49.2	0	59,523
2200	1398.5	67	52.2	0	57,592
2300	1396.3	65	55.8	0	57,376
2400	1400.5	62	59.6	0	55,743
2500	1358.8	60	62.7	0	53,619
2600	1337.8	57	63.4	0.005	52,131
2700	1288.5	54	63.3	0.16	50,343
2800	1252.3	51	62.7	0.19	49,103
2900	1230.5	48	62.7	0.21	48,028

[21] Total is the total habitat for the pre-restoration reach.

Pre-restoration fall-run Chinook salmon fry rearing WUA (ft^2)[22]

Flow (cfs)	Site 1	Site 2	Site 3	Site 4	Total
100	17672	5210	498.4	4768	134,994
200	14475	5253	566.2	5931	124,359
300	13581	4779	566.2	6760	120,577
400	12573	4370	551.2	7545	116,975
500	11486	3778	467.9	8331	113,870
600	11141	3541	550.9	8912	114,808
700	10835	3348	535.3	9472	116,279
800	10195	3229	587.8	9612	115,016
900	10246	3132	855.7	9591	116,338
1000	9871	3046	983.7	9558	114,500
1100	9463	3089	1182	9472	112,318
1200	9332	3089	1534	9300	111,177
1300	9244	2971	1597	9171	109,615
1400	9130	2992	1665	9074	108,414
1500	9187	2928	1953	9031	107,446
1600	8901	2906	1989	9009	106,233
1700	8602	2885	1895	8912	104,310
1800	8682	2842	1816	8719	102,603
1900	8561	2809	1784	8514	100,780
2000	8420	2788	1753	8245	98,544
2100	8348	2648	1543	8041	95,729
2200	8247	2648	1406	7901	93,734
2300	8339	2605	1453	7782	93,116
2400	8433	2519	1411	7653	92,549
2500	8213	2508	1446	7567	91,437
2600	8199	2443	1543	7470	91,493
2700	8089	2357	1467	7416	90,497
2800	7755	2282	1368	7266	87,602
2900	7378	2174	1304	7276	85,395

[22] Total is the total habitat for the pre-restoration reach.

Pre-restoration fall-run Chinook salmon juvenile rearing WUA (ft^2)[23]

Flow (cfs)	Site 1	Site 2	Site 3	Site 4	Total
100	4063	979.5	109.3	656.6	29,102
200	3774	1378	124.6	850.3	30,299
300	3586	1475	140.0	1033	31,267
400	3375	1410	145.5	1173	30,419
500	3264	1238	134.6	1378	29,448
600	3241	1162	134.9	1615	29,822
700	3257	1066	153.3	1937	31,081
800	3305	914.9	146.1	2099	31,164
900	3334	882.6	154.2	2174	31,673
1000	3259	893.4	177.6	2228	31,875
1100	3099	861.1	206.1	2260	30,892
1200	3051	871.9	279.4	2314	31,200
1300	3017	861.1	304.6	2347	31,285
1400	2995	861.1	324.6	2379	31,403
1500	2972	828.8	369.8	2379	31,084
1600	3215	839.6	420.4	2368	31,494
1700	3228	850.3	437.7	2347	31,377
1800	3160	861.1	435.9	2336	31,238
1900	3141	882.6	435.3	2293	31,089
2000	3106	904.2	458.1	2196	30,664
2100	3100	904.2	446.8	2196	30,630
2200	3028	904.2	439.7	2153	29,921
2300	2944	882.6	462.7	2120	29,104
2400	2841	861.1	469.6	2110	28,660
2500	2715	850.3	466.3	2099	28,180
2600	2657	839.6	484.5	2110	28,210
2700	2611	828.8	478.5	2120	28,079
2800	2575	828.8	445.9	2131	27,875
2900	2524	818.1	433.0	2131	27,617

[23] Total is the total habitat for the pre-restoration reach.

Post-restoration fall-run Chinook salmon spawning WUA (ft^2)[24]

Flow (cfs)	Site 1 (pre-rest)	Site 1 (post-rest)	Site 2	Site 3	Site 4	Total
100	40.3	7330	12335	2687	14198	109,974
200	94.7	3421	7621	3297	10602	77,085
300	216.4	3628	6674	2816	9849	71,785
400	617.8	3088	5927	2780	9757	66,908
500	729.8	2732	6232	2263	9048	63,357
600	681.4	2998	5021	2199	8544	57,574
700	713.6	3068	4772	1990	8287	56,252
800	734.1	3330	5555	1795	7756	57,185
900	745.9	3218	5508	1769	7749	56,210
1000	745.9	3557	5422	1711	7762	56,382
1100	770.7	3587	5425	2086	6572	53,798
1200	737.3	3362	4633	1824	7098	51,910
1300	744.9	3267	4998	1785	6366	50,292
1400	634.0	3546	5029	1586	6713	51,720
1500	670.6	4302	4752	1685	6984	53,719
1600	643.7	4337	4626	1506	6613	52,086
1700	613.5	3717	4763	1562	5890	48,498
1800	514.5	3092	5077	1560	5323	45,781
1900	487.6	2847	4853	1614	5059	43,712
2000	571.6	2960	4893	1678	4835	43,691
2100	727.3	3239	4490	1732	4646	42,828
2200	782.5	3648	4191	1702	4503	42,315
2300	740.6	3154	3970	1640	4461	39,694
2400	628.6	3391	3644	1677	4543	39,826
2500	668.4	3100	3272	1696	4704	38,375
2600	618.9	3324	3048	1711	4999	39,353

[24] Total is the total habitat for the post-restoration reach. Total does not include pre-restoration portion of Site 1 or off-channel area portion of Site 3.

Post-restoration fall-run Chinook salmon fry rearing WUA (ft^2)[25]

Flow	Site 1 (pre-rest)	Site 1 (post-rest)	Site 2	Site 3	Site 4	Total
100	2122.6	2274	2298	1600	2483	24,209
200	2198.7	1999	1896	1548	2167	20,329
300	3750.5	1982	1800	1802	1955	19,341
400	2667.9	1971	1881	1874	1897	19,409
500	1909.3	1916	1516	1794	1819	17,662
600	1782.1	1889	1625	1807	1863	18,009
700	1545.6	1776	1849	1853	1794	18,156
800	1416.0	1647	1775	1800	1795	17,262
900	1288.0	1766	1691	1814	1703	17,135
1000	1342.5	1736	1717	1796	1719	17,323
1100	1302.4	1711	1612	1746	1892	17,482
1200	1336.3	1729	1793	1864	1863	18,067
1300	1348.7	1817	1779	1737	1879	18,097
1400	1405.2	1859	1762	1697	1750	17,699
1500	1400.2	1741	1889	1642	1503	16,985
1600	1413.0	1626	2018	1632	1542	17,080
1700	1434.7	1710	2043	1601	1664	17,794
1800	1417.0	1778	1851	1551	1747	17,697
1900	1468.8	1780	1958	1483	1760	17,989
2000	1424.9	1758	1914	1441	1543	17,131
2100	1132.4	1747	1976	1402	1475	17,179
2200	1047.8	1678	1837	1364	1602	16,935
2300	949.9	1623	1766	1332	1674	16,738
2400	978.9	1549	1739	1284	1738	16,557
2500	916.2	1604	1794	1242	1464	15,997
2600	1110.3	1669	1862	1250	1093	15,356

[25] Total is the total habitat for the post-restoration reach. Total does not include pre-restoration portion of Site 1 or off-channel area portion of Site 3.

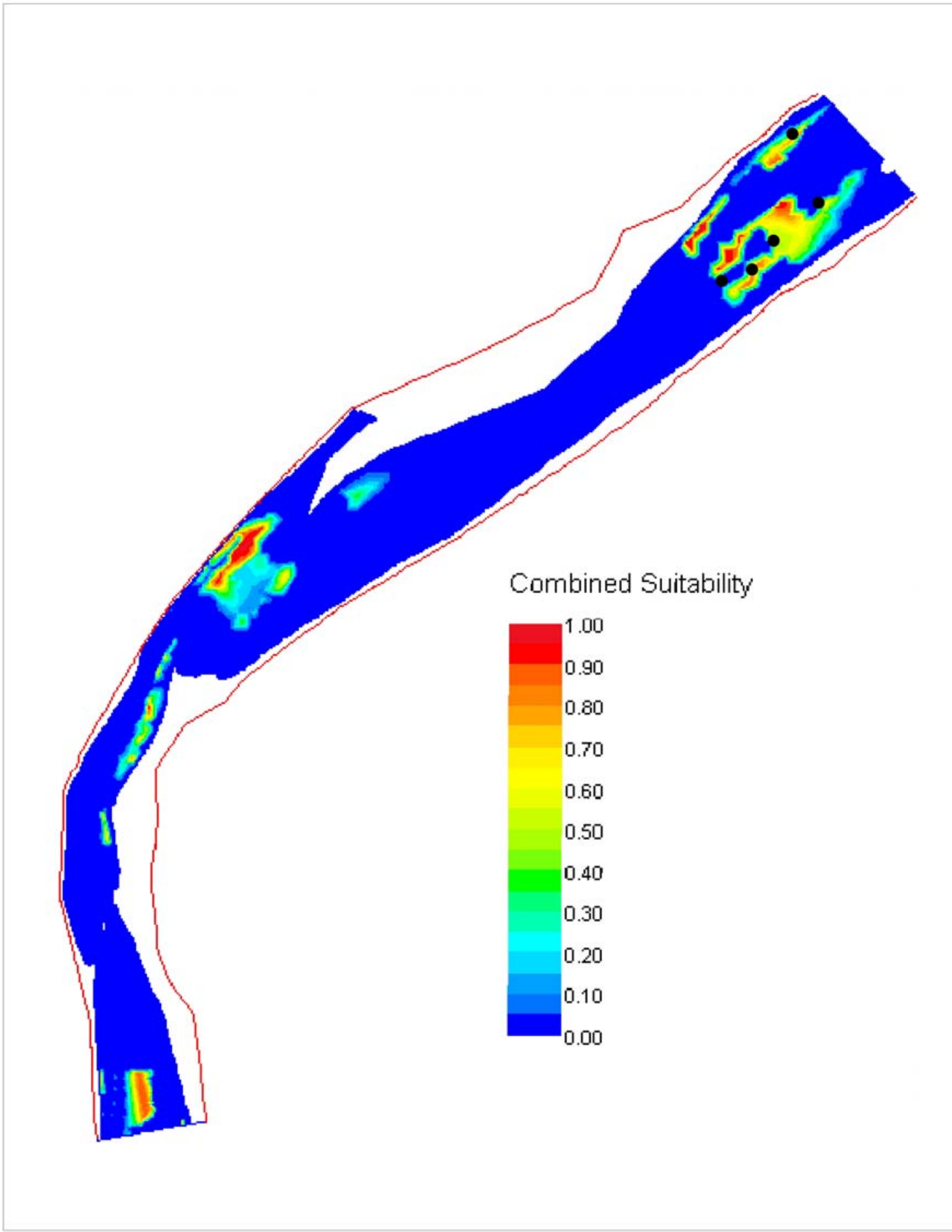
Post-restoration fall-run Chinook salmon juvenile rearing WUA (ft^2)[26]

Flow (cfs)	Site 1 (pre-rest)	Site 1 (post-rest)	Site 2	Site 3	Site 4	Total
100	377.2	655	728	281	736	7307
200	812.6	534	650	269	747	6526
300	1026.6	555	566	366	751	6455
400	1226.8	557	629	422	703	6571
500	1227.6	523	479	414	664	5808
600	1187.5	496	429	415	611	5365
700	1151.5	470	486	451	561	5249
800	1092.9	418	452	429	536	4805
900	1002.8	438	436	449	497	4658
1000	950.5	418	442	409	451	4465
1100	971.7	428	391	390	499	4437
1200	970.7	438	383	496	464	4375
1300	982.1	463	341	490	542	4511
1400	1015.2	476	325	495	541	4488
1500	1050.2	443	352	478	500	4362
1600	1071.4	409	392	480	457	4218
1700	1074.9	430	438	485	436	4368
1800	1078.6	418	388	483	418	4136
1900	1114.6	437	414	475	431	4294
2000	1176.1	440	393	470	415	4164
2100	1079.2	428	437	465	367	4118
2200	881.3	394	398	454	368	3890
2300	735.9	367	363	442	407	3804
2400	642.5	339	349	435	457	3812
2500	573.8	350	351	425	433	3766
2600	561.4	334	394	418	386	3708

[26] Total is the total habitat for the post-restoration reach. Total does not include pre-restoration portion of Site 1 or off-channel area portion of Site 3.

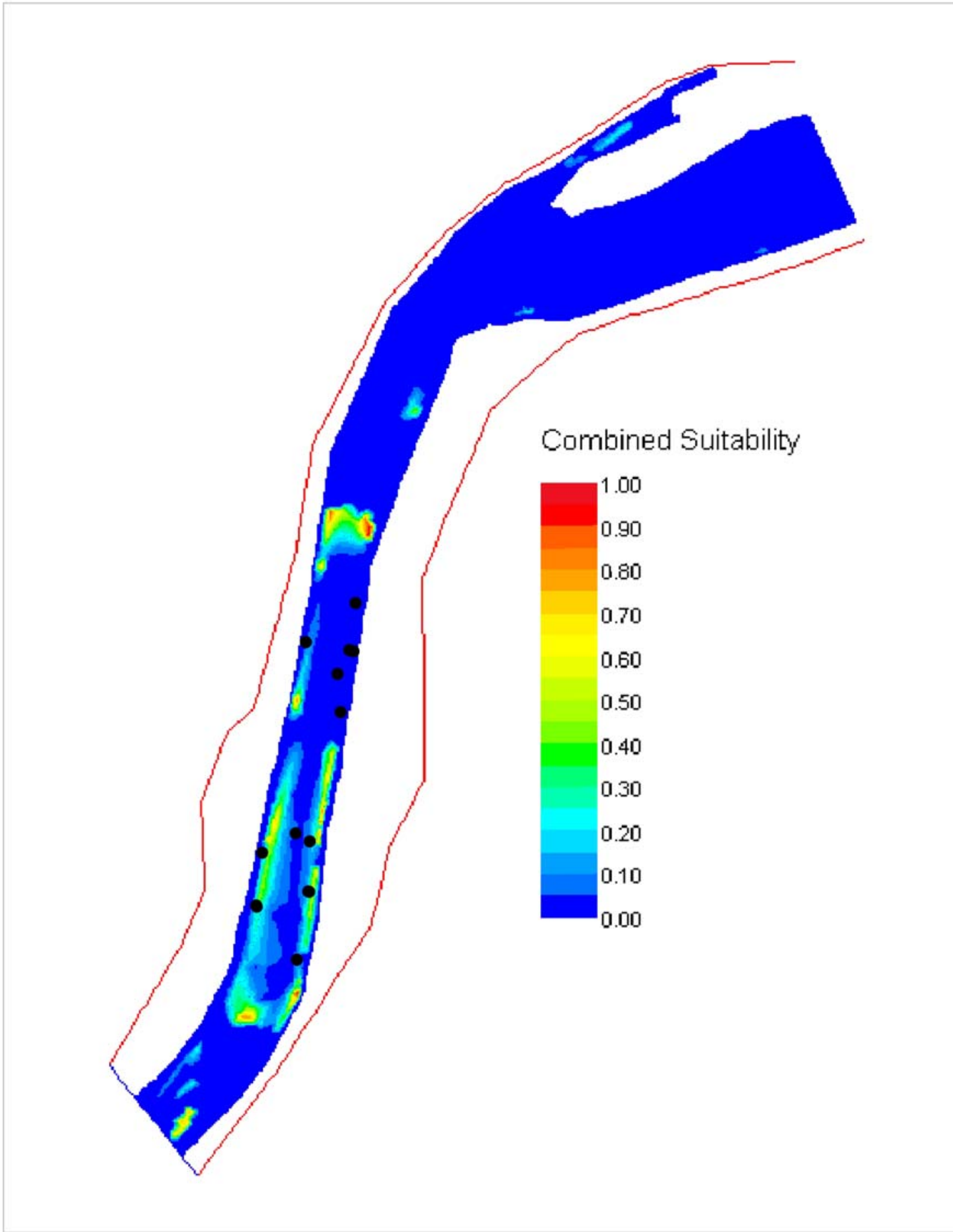
APPENDIX I
COMBINED HABITAT SUITABILITY OF REDDS, FRY AND JUVENILES

Pre-restoration Site 1 redds



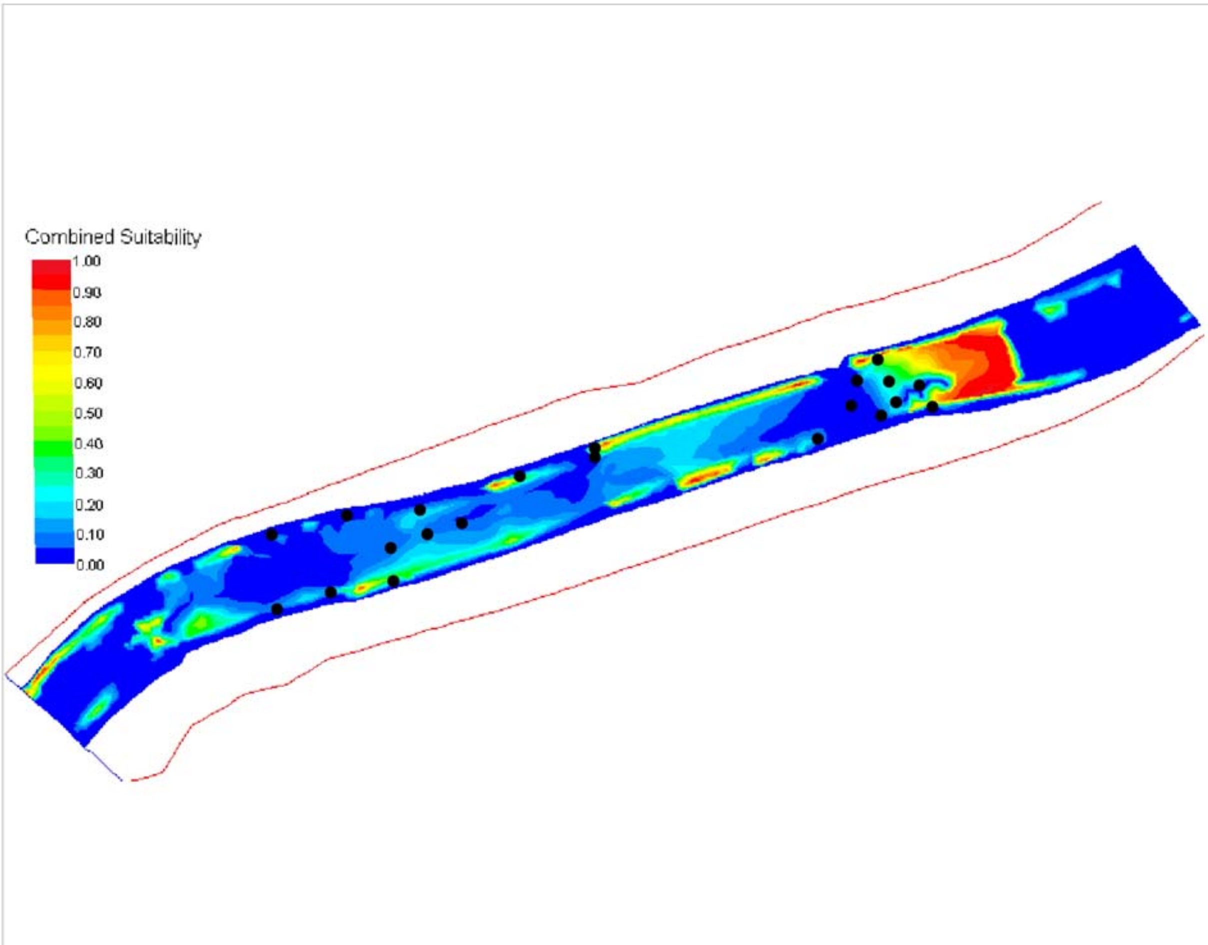
. = redd locations. Pre-restoration sites 2, 3 and 4 did not have any redds.

Post-restoration Site 1 redds



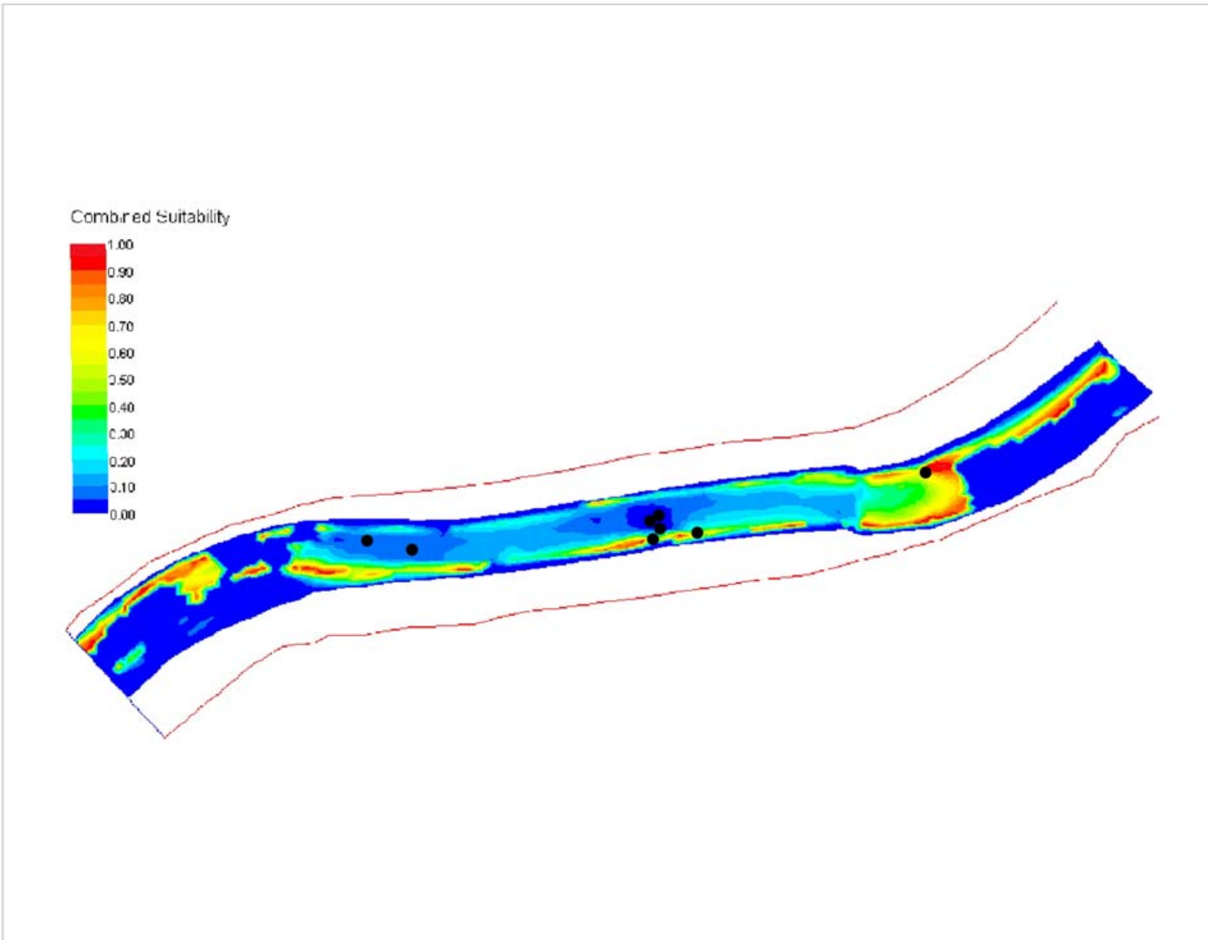
. = redd locations.

Post-restoration Site 2 redds



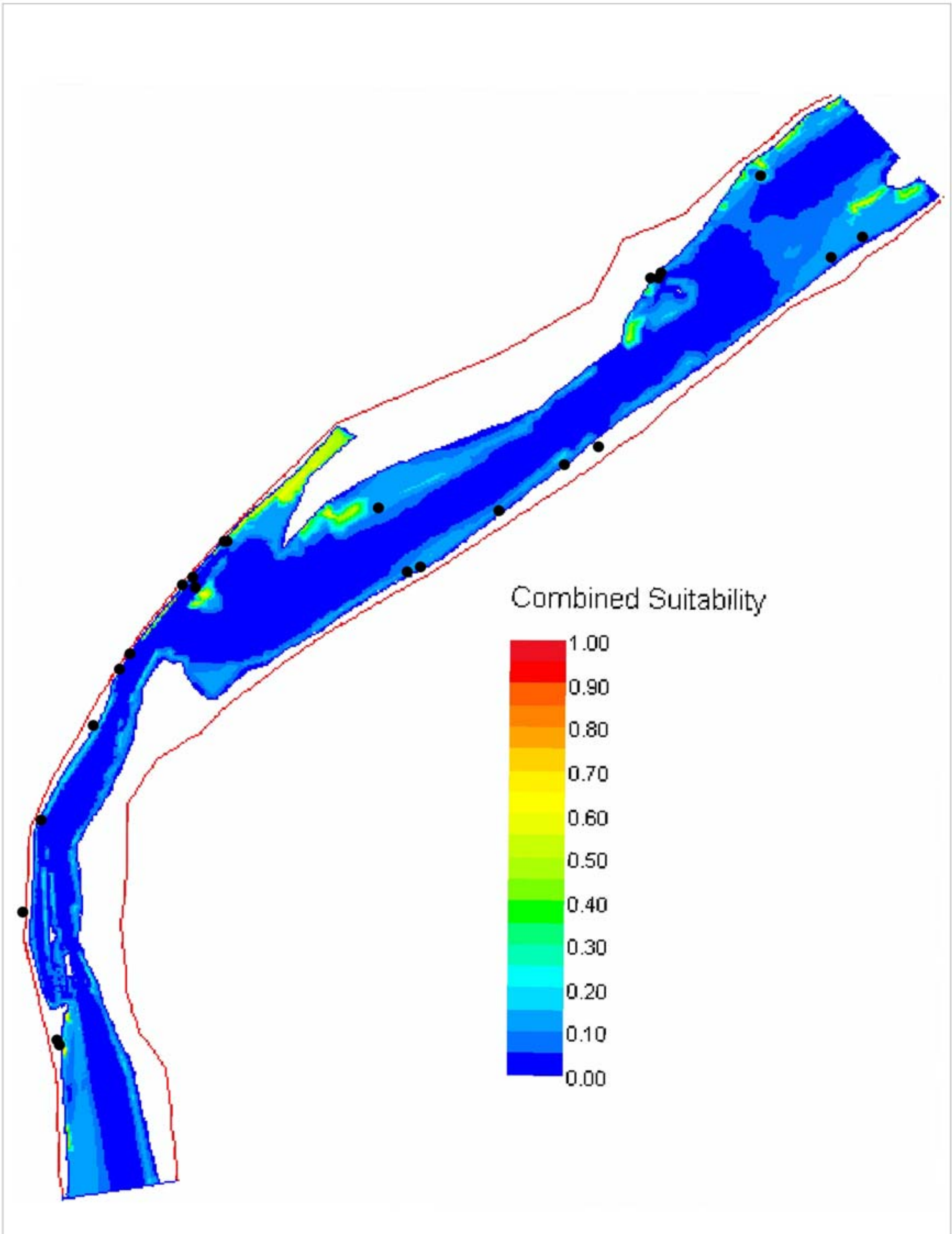
● = redd locations. Post-restoration site 3 did not have any redds.

Post-restoration Site 4 redds



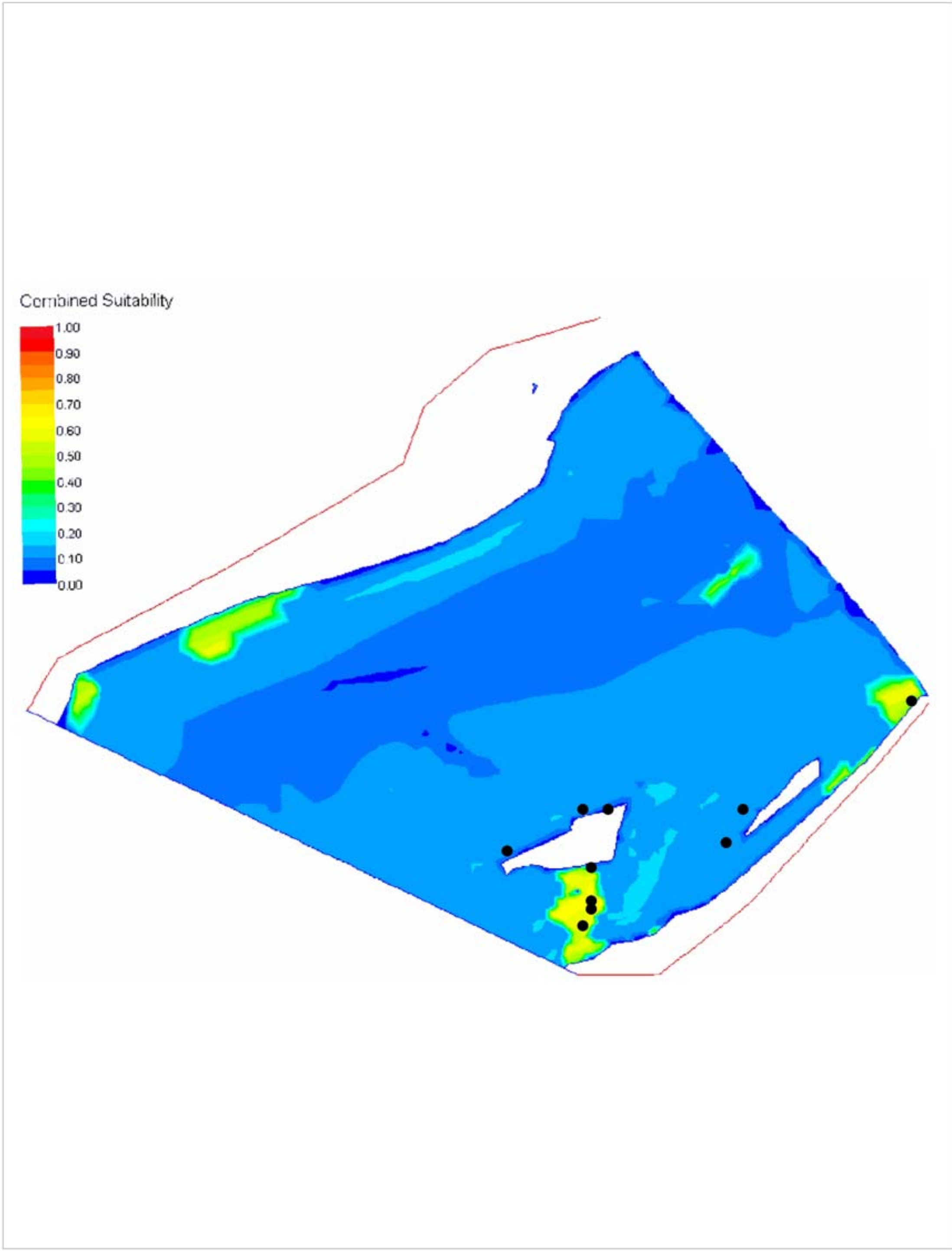
● = redd locations.

Pre-restoration Site 1 fry



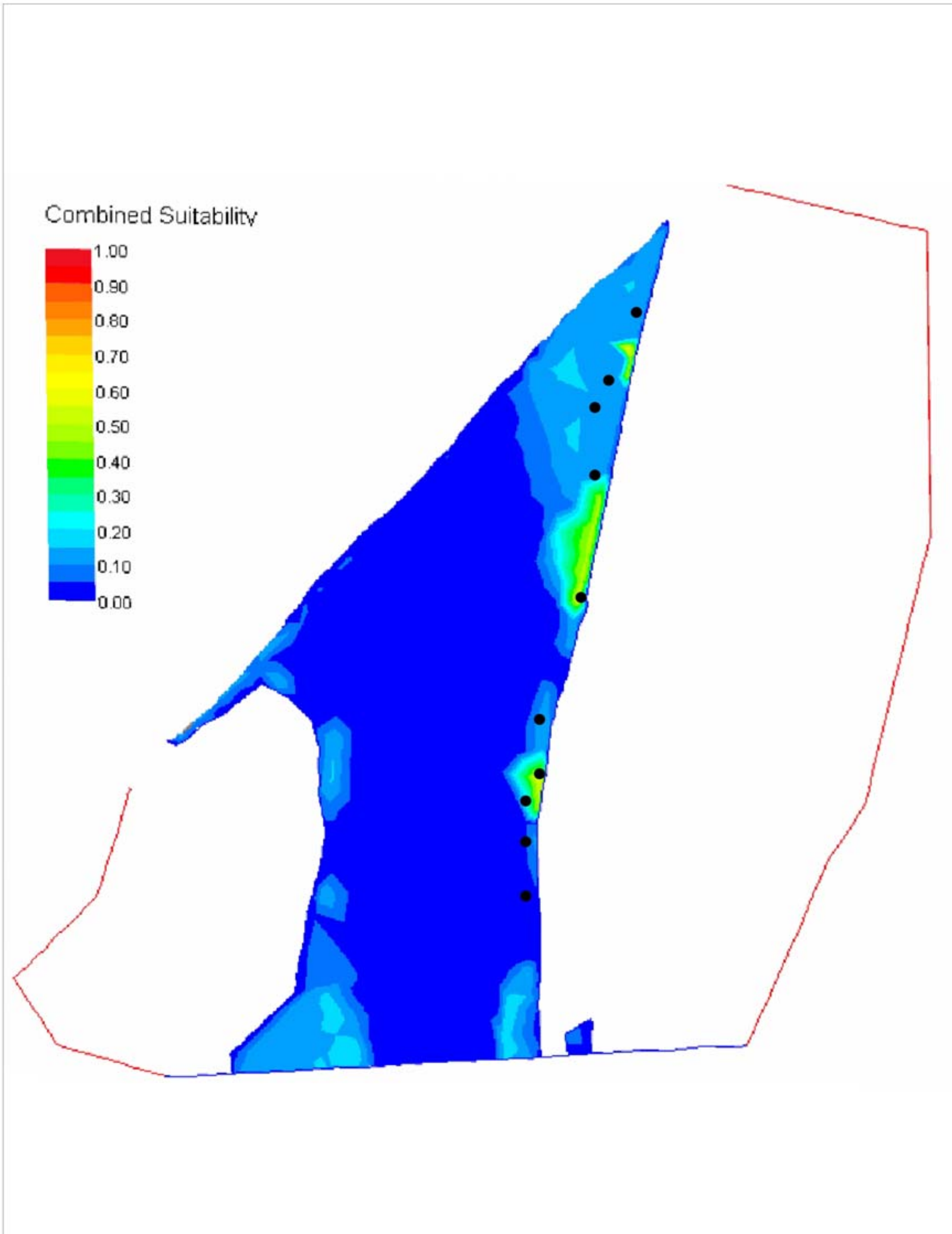
. = fry locations

Pre-restoration Site 2 fry



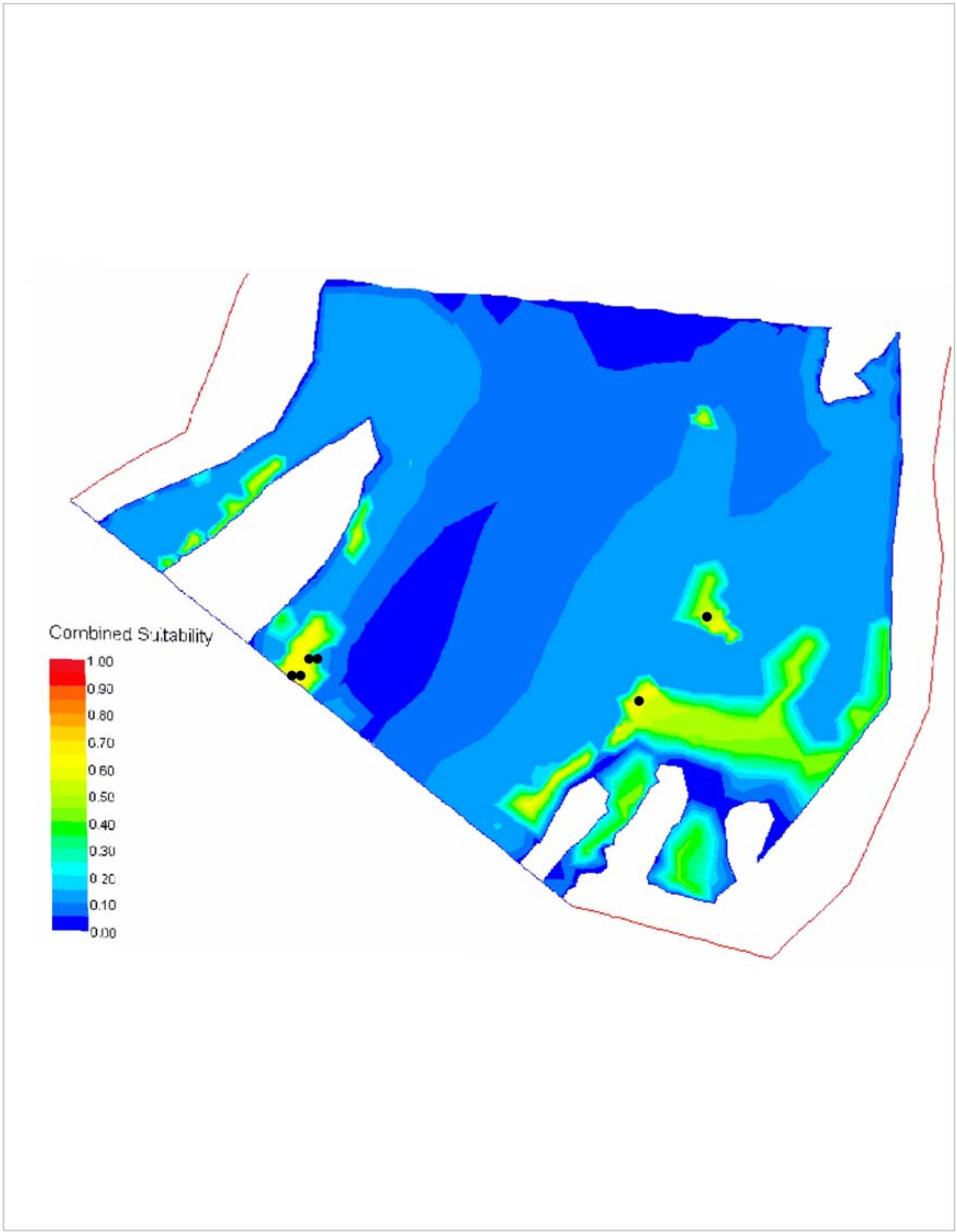
. = fry locations

Pre-restoration Site 3 fry



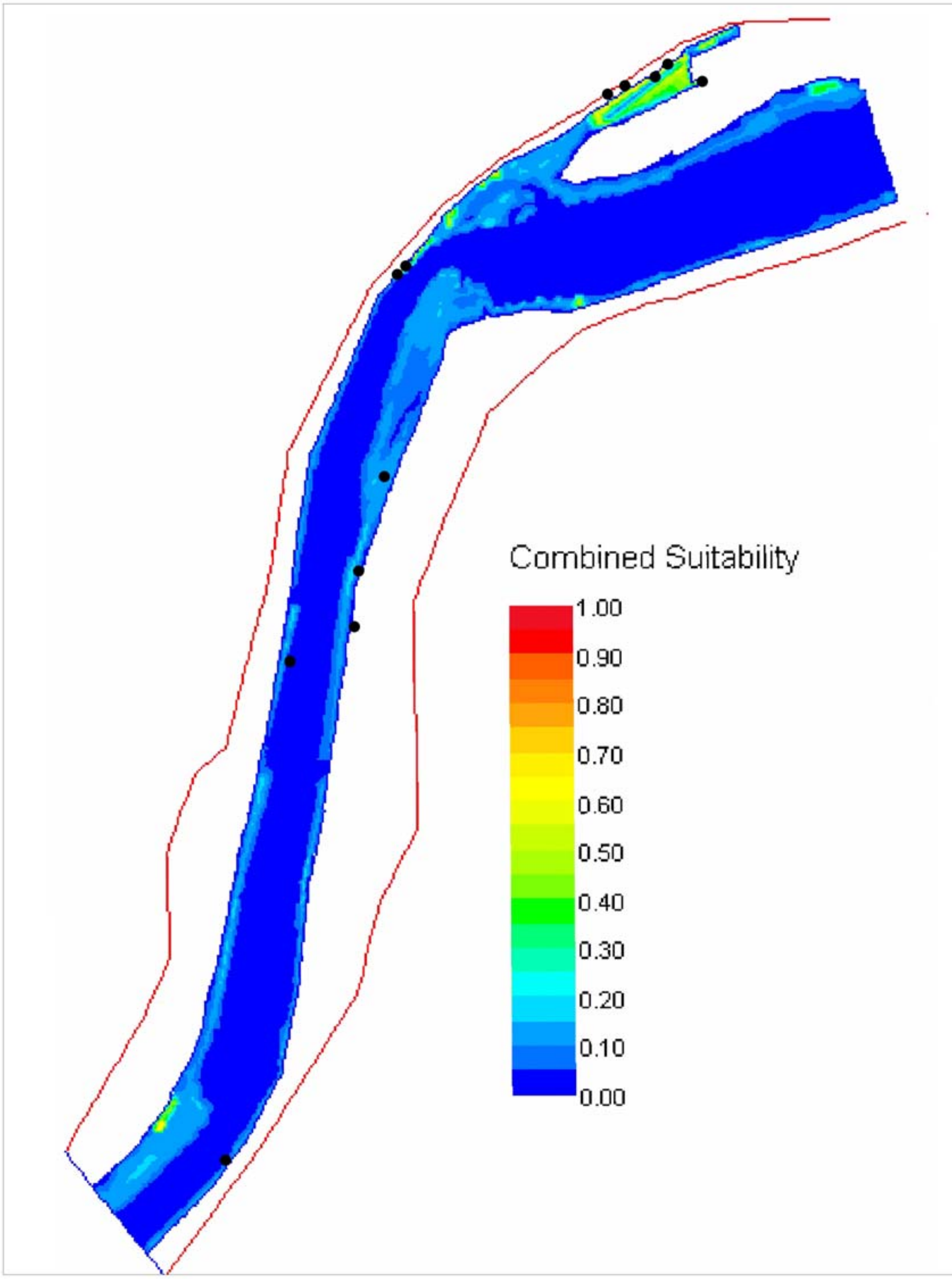
. = fry locations

Pre-restoration Site 4 fry



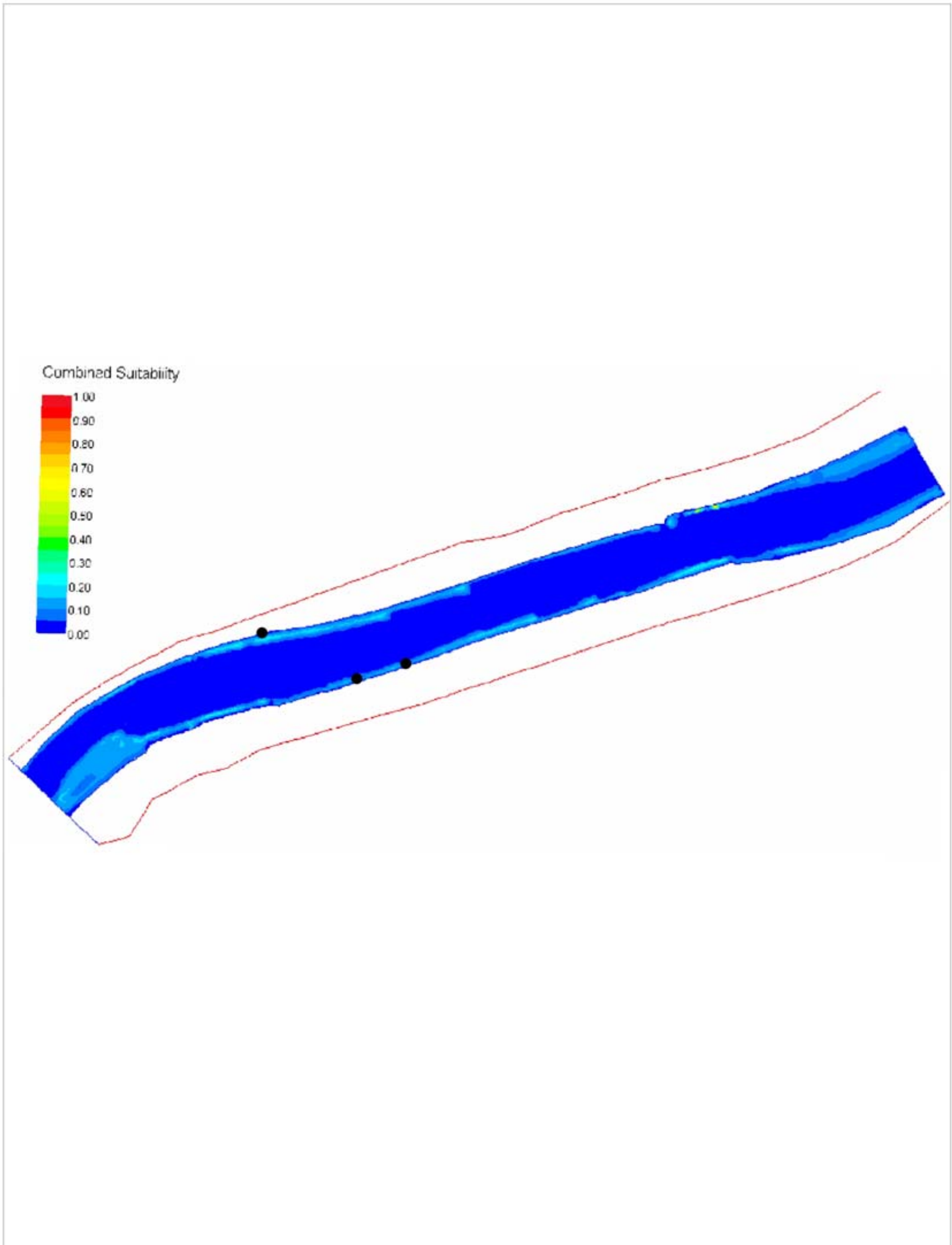
. = fry locations

Post-restoration Site 1 fry, Q = 222 cfs



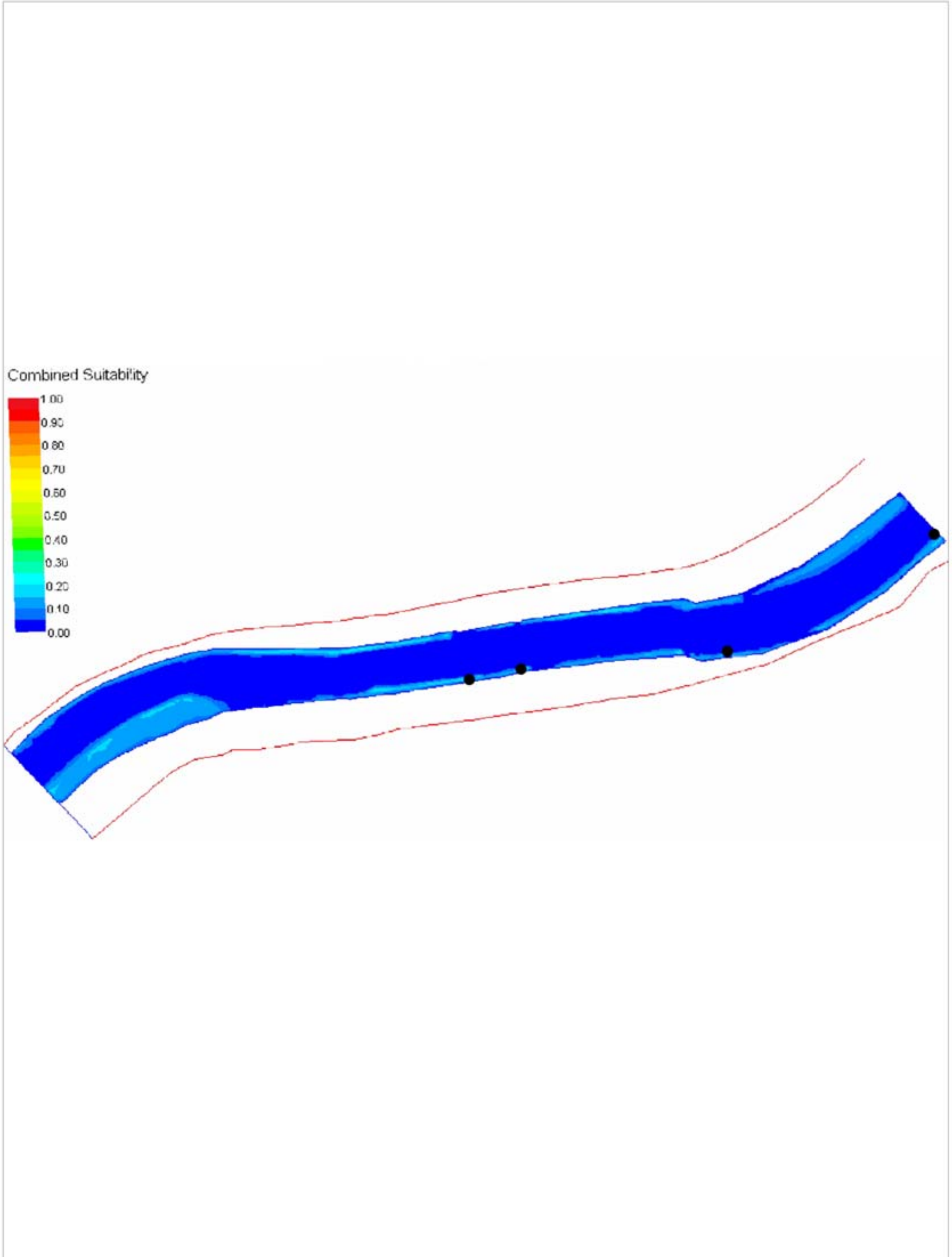
. = fry locations. No fry were observed at 577 cfs.

Post-restoration Site 2 fry, Q = 222 cfs



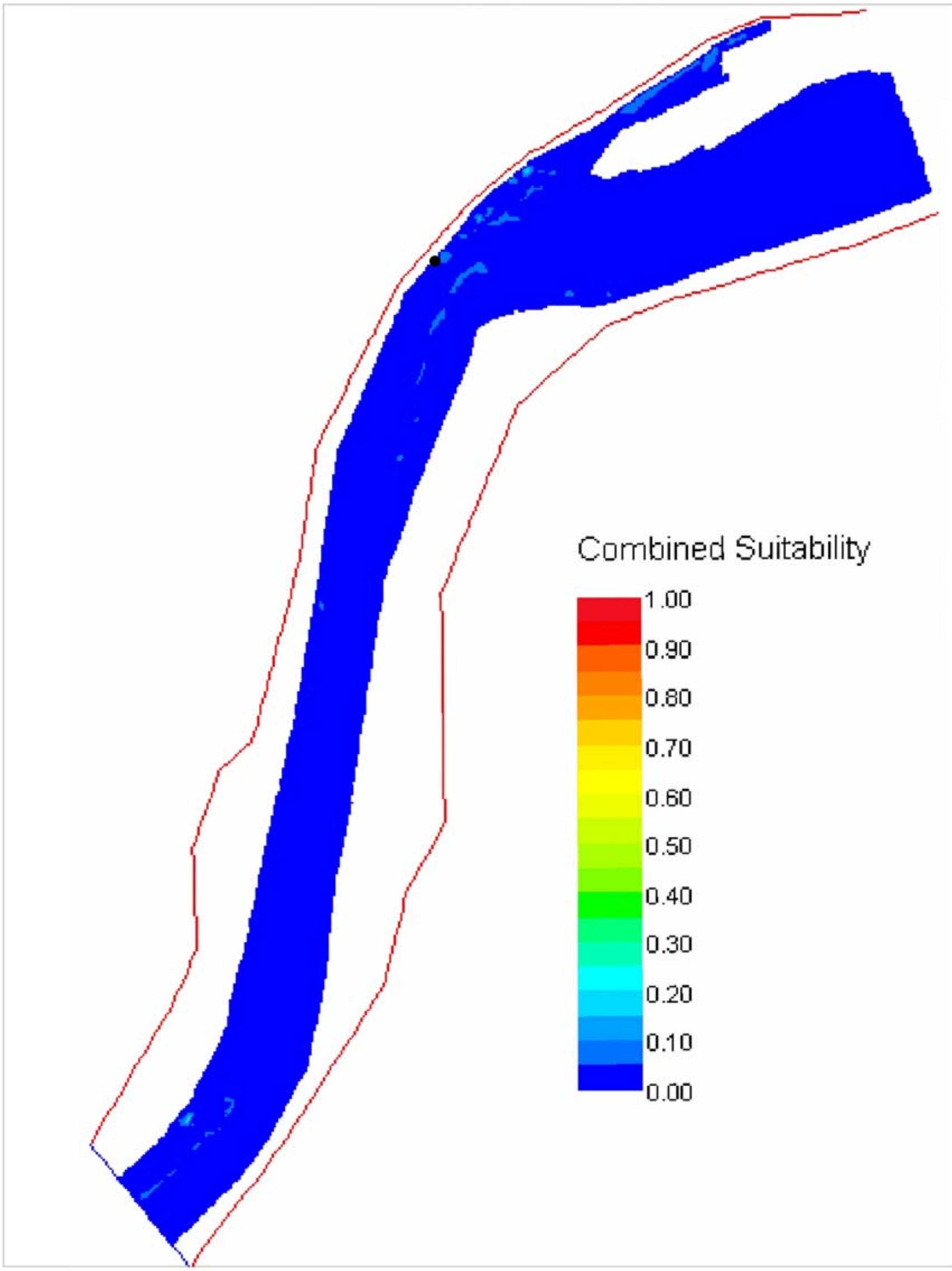
. = fry locations. No fry were observed at 665 cfs for Post-restoration Site 2 and no fry were observed during either snorkel survey for Post-restoration Site 3.

Post-restoration Site 4 fry, Q = 222 cfs



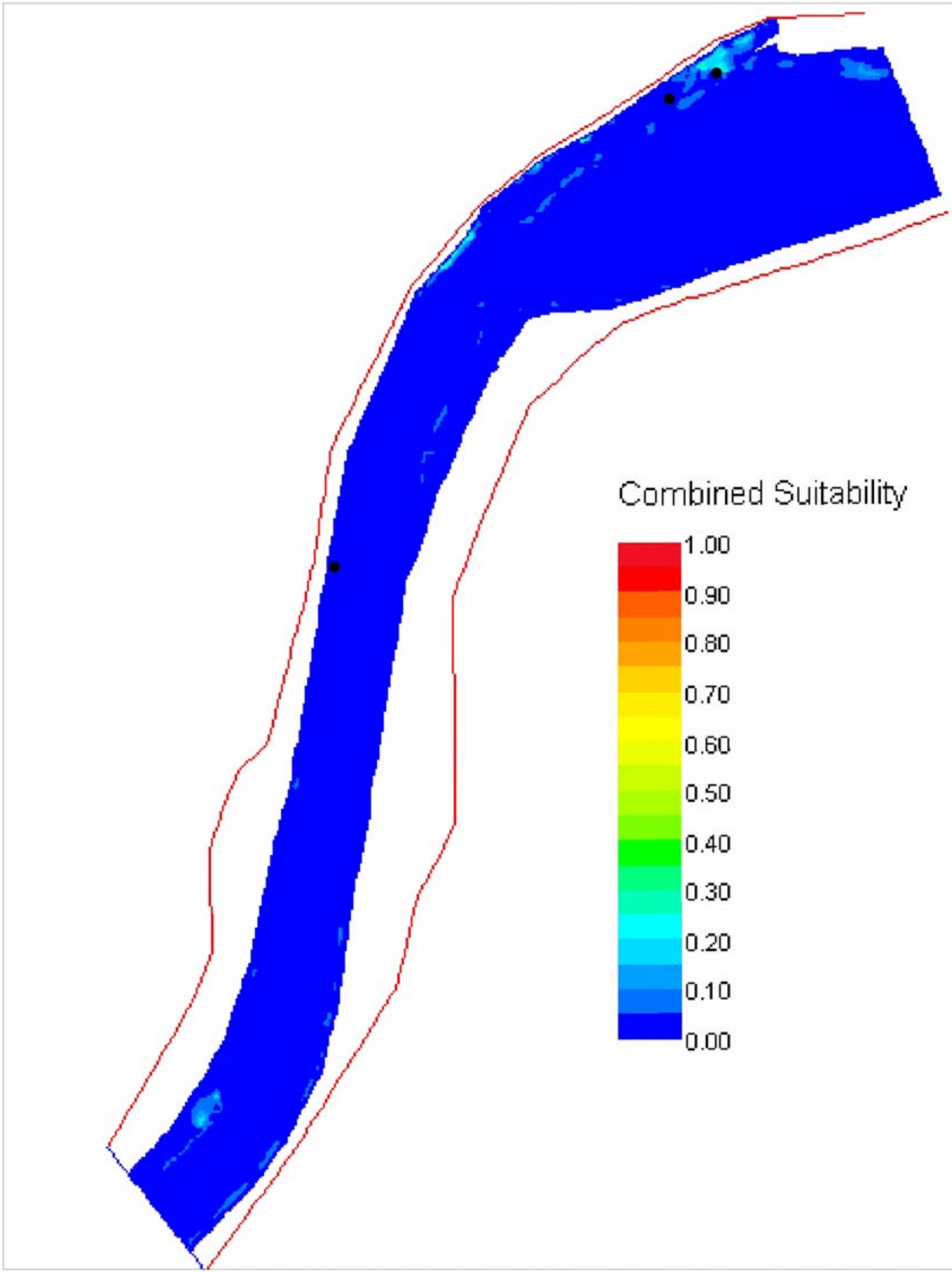
. = fry locations. No fry were observed at 665 cfs

Post-restoration Site 1 juvenile, Q = 222 cfs



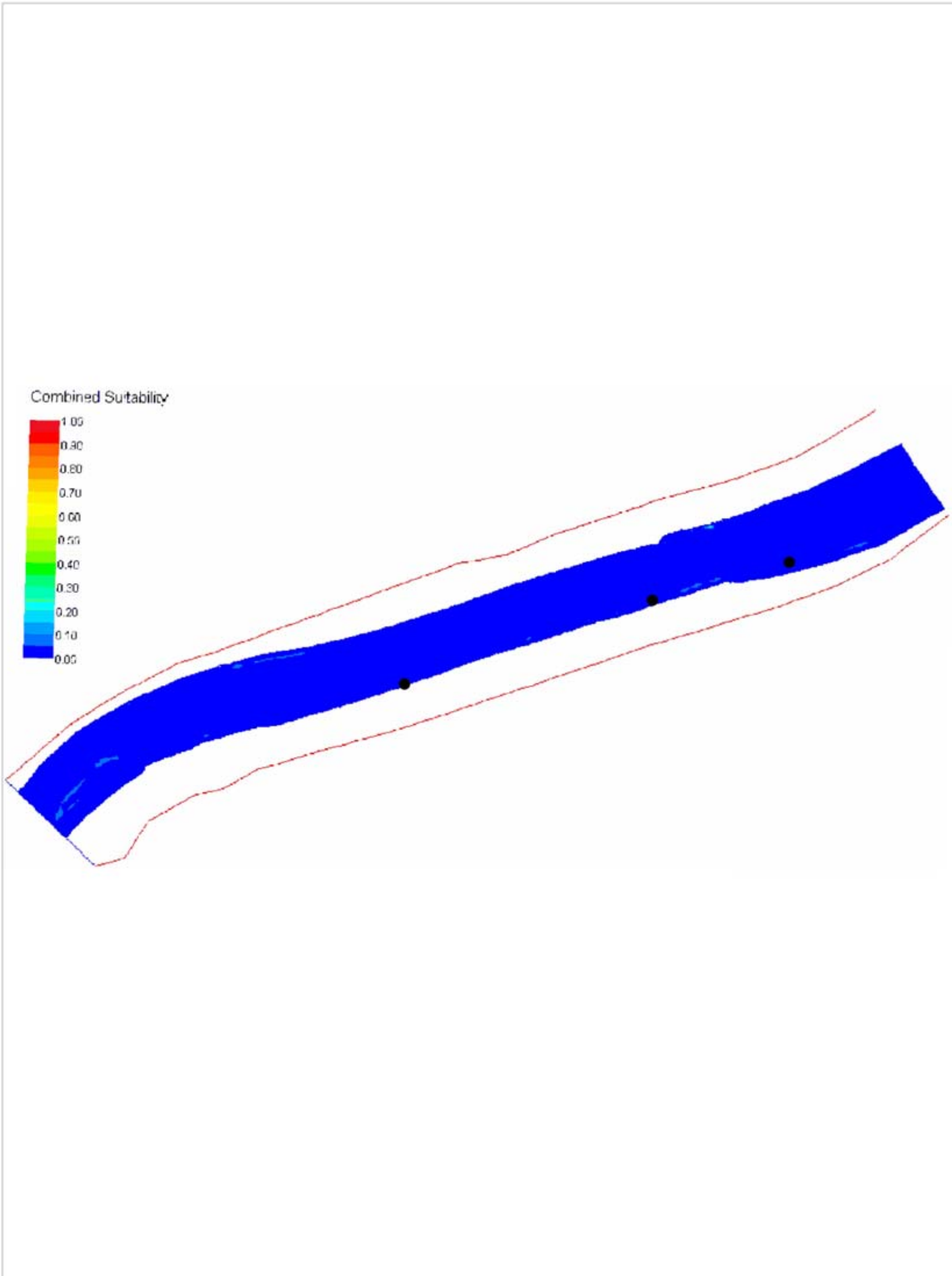
. = juvenile locations

Post-restoration Site 1 juvenile, Q = 577 cfs



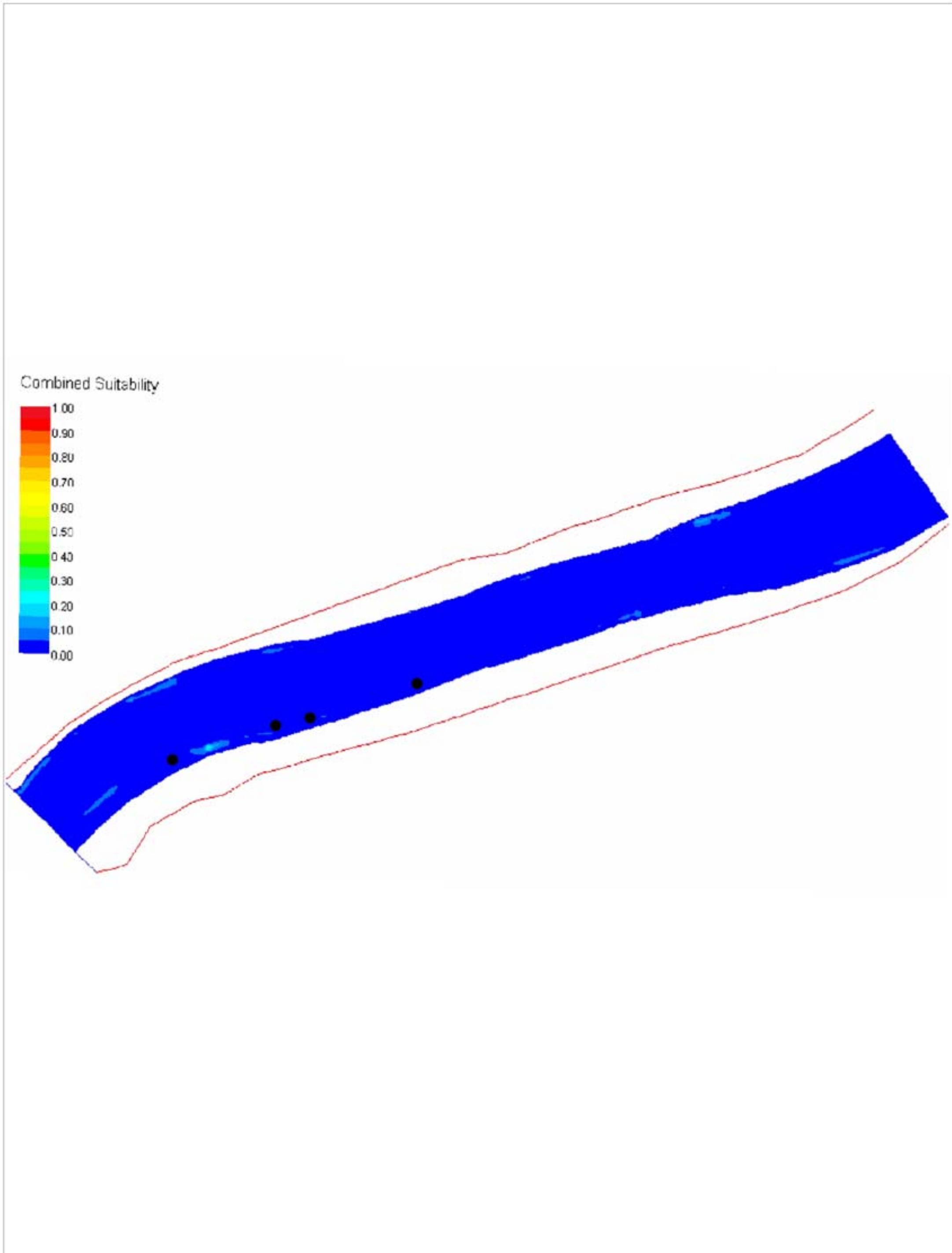
. = juvenile locations

Post-restoration Site 2 juvenile, Q = 222 cfs



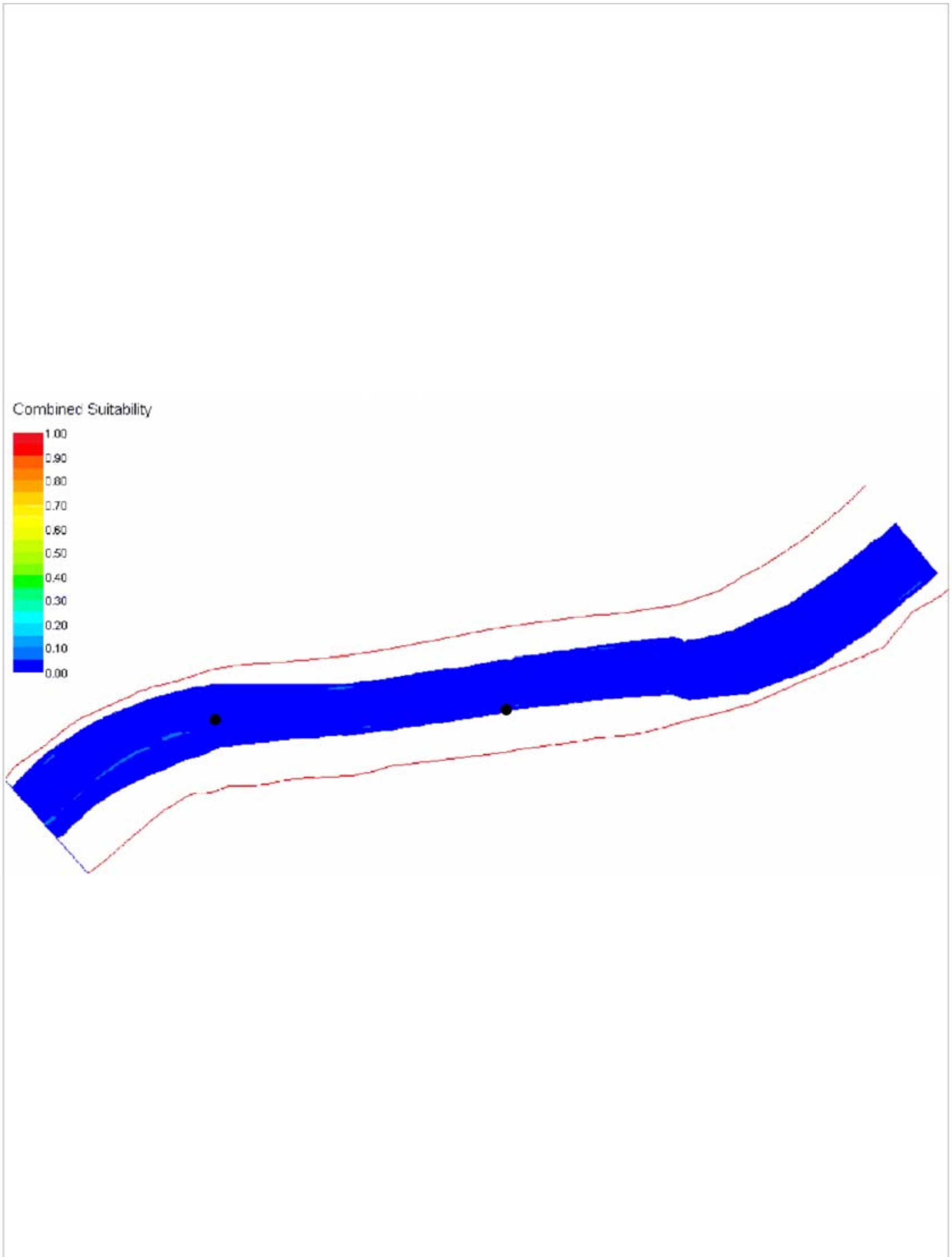
. = juvenile locations.

Post-restoration Site 2 juvenile, Q = 665 cfs



. = juvenile locations. No juveniles were observed in Post-restoration Site 3.

Post-restoration Site 4 juvenile, Q = 222 cfs



. = juvenile locations. No juveniles were observed in Post-restoration Site 4 at 665 cfs.